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BIGGER AND BETTER

Specifying things bigger and better brings in its wake definite problems. Here are T.V.A.'s specifications for the Chickamauga generators and how they were met. For details on the field erection of these generators, see the article beginning on page 9.

S. H. Mortensen, **Engineer-in-Charge, A-C Design**

ELECTRICAL DEPARTMENT • ALLIS-CHALMERS MANUFACTURING COMPANY

● The water wheel generator installation in the Chickamauga powerhouse represents the latest present-day practice in the design of large, slow speed machines. These 30,000 kva, 75 rpm generators are driven by propeller type water wheels. This rating, combined with the slow operating speed and the requirement for large alternator rotor WR^2, resulted in machines of such large physical dimensions that it became expedient to build them in the Chickamauga station.

Because of the size and special features of these generators, a brief description of their construction and erection may be of general interest. The electrical and mechanical design of the Chickamauga machines is based upon the following specifications, which were issued by the T. V. A. engineers.

The T. V. A. Specifications

Type and Rating. Each generator shall be of the vertical shaft, water turbine driven, totally enclosed, water-cooled type, with direct-connected main exciter and pilot exciter and shall have the following rating:

(a) Continuous output at 0.9 p.f., rated speed and voltage with temperature rise of not over 60 C above 40 C air leaving the coolers ....30,000 kva

(b) Voltage between phases... .... 13,800 volts

(c) Amperes per phase..1255 amps

(d) Speed ....75 rpm

(e) Phases ....3 phase

(f) Frequency ....60 cycles

(g) Nominal excitation voltage ....250 volts

Electrical Requirements. Each generator shall have the following electrical characteristics and features:

(a) Continuous output at 0.9 p.f., at rated speed and at 95 to 105 percent of rated voltage without injury with 30 C water to coolers and 40 C air leaving the coolers ....34,500 kva

(b) Continuous output, over-excited, at rated speed, field and voltage when operating as a synchronous condenser not less than ....16,500 kva

(c) Continuous output when charging a transmission line, at rated speed and 100 percent of rated voltage without being completely self-excited or unstable, not less than ....26,400 kva

(d) No-load balanced telephone interference factors not greater than 50

(e) No-load residual telephone interference factors not greater than 30

(f) Deviation factor of wave form, measured in percent from line to line on open circuit at rated voltage and speed, not greater than 10

(g) Nominal exciter response ratio 1.0

(h) Ceiling voltage of exciter when delivering rated current not less than..............325 volts

(i) Short circuit ratio shall not be less than 1.1

Armature windings shall be star-connected and designed for either grounded or ungrounded neutral operation.

Insulation of generator armature and field shall be AIEE Standards Class B to meet tests specified.

Mechanical Requirements. Each generator shall have the following mechanical characteristics and features:

(a) Flywheel effect (WR^2) of rotating parts of generator, shaft, and exciters shall be highest available without additional cost, but not less than.... ....75,000,000 lb ft²

(b) Maximum runaway speed for period of one hour without injury ....207 rpm

(c) Rotation, looking down on unit .... Clockwise

(d) Over-all diameter of generator completely assembled shall be not more than..........560 in.

(e) Internal diameter of stator shall not be less than ....300 in.

The generator shall be designed for operation with a turbine having the following dimensions and characteristics:

(f) Diameter of turbine inner head cover ....288¼ in.

(g) Diameter of turbine pit..306 in.

(h) Weight of rotating parts... .... 420,000 lb

(i) Maximum output of turbine ....42,000 hp

The stator windings shall be connected with both ends of two equal groups of conductors of each phase brought out to terminals. The neutral ends shall be bussed within the generator housing. The neutral bus shall be insulated from ground to permit operation with either grounded or ungrounded neutral.

Damper windings shall be provided to improve stability under fault conditions and specifically to reduce voltage distortion under conditions of single-phase fault. They shall be designed for a ratio of quadrature axis subtransient reactance to direct axis subtransient reactance equal to approximately 1.3. They shall be of low resistance, rugged construction, and preferably without bolted joints or connections between poles.

Generator as designed

Figure 1 shows the design evolved to fulfill these requirements. These generators are of a fabricated construction, using rolled steel plates and welded structures in place of castings. They are of the umbrella type, which permits rotor removal without disturbing the shaft and bearing alignment. This design also

These are located below the rotor and are supported on a bearing bracket, or bridge. The latter, in addition to supporting the rotor, also forms the oil chamber that encloses the thrust and guide bearings and the bearing oil cooling coils. The construction of the bridge, bearings, and cooling coils permits removal of the latter through normally covered openings in the sides of the oil container.

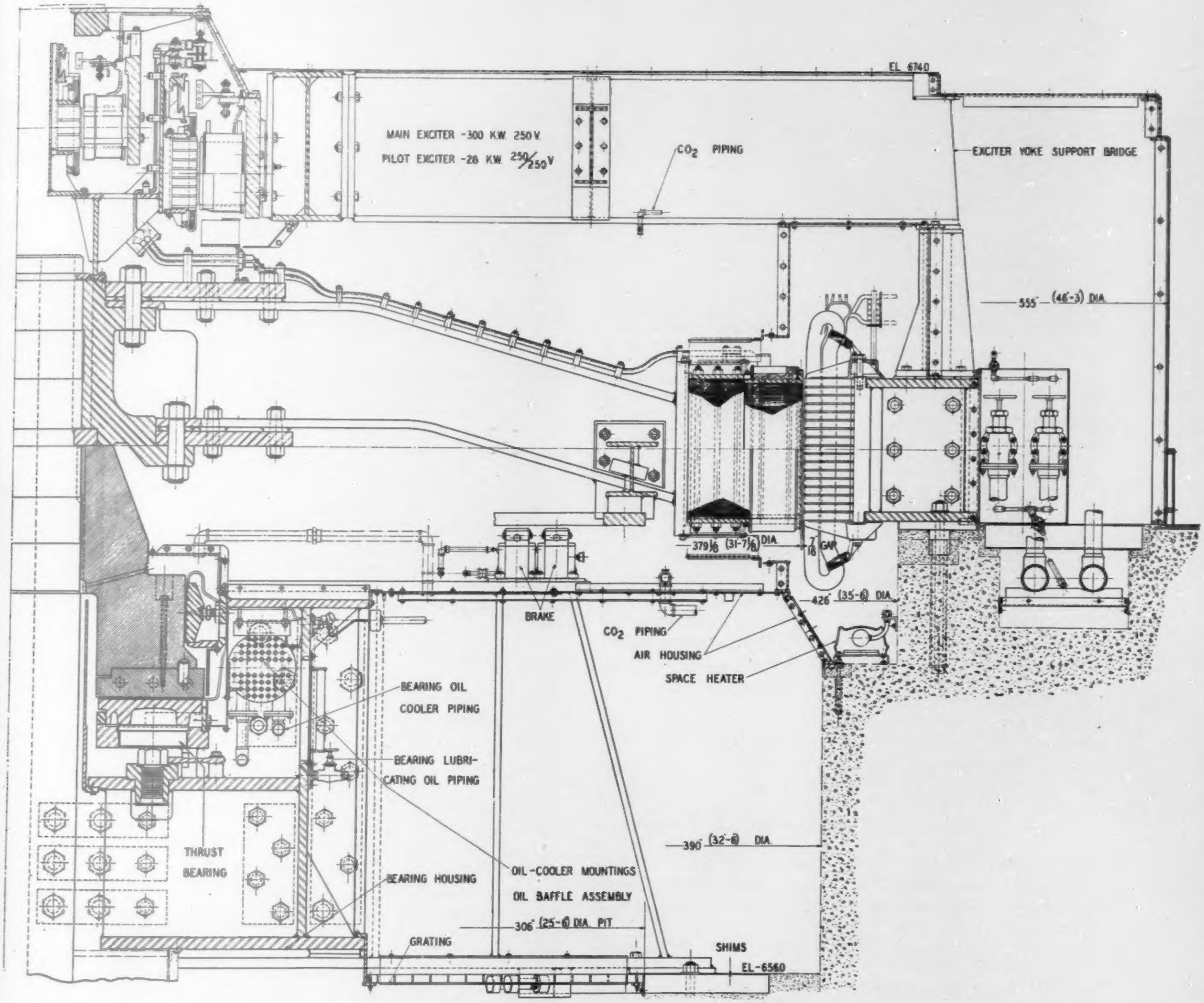


Fig. 1—Sectional View of Chickamauga Generator.

makes possible the extraction of the bearing housing, shaft, and bearings in one piece, without changing the unit alignment. The 2,050,000 lb weight of the rotating parts and hydraulic thrust is carried on a 93 in. dia flat adjustable shoe type Kingsbury thrust bearing, which teams with a sectionalized generator guide bearing 84 in. dia and 14 in. long.

Spider construction

The rotor spider is composed of 16 arms bolted to a solid hub on the rotor shaft. The outer parts of the arms carry a flange for mounting the rotor rim, which is built up of segmental laminations punched so as to accommodate the pole dovetails and through bolts for clamping the core. The pole rim is not anchored to

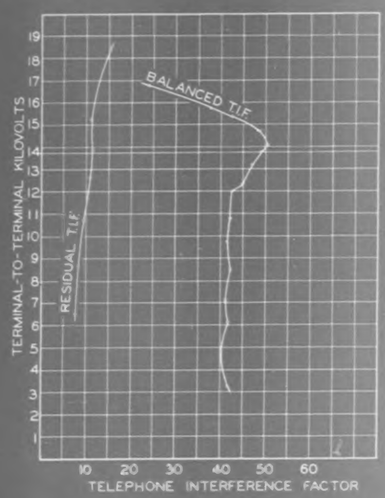


Fig. 2—Balanced and Residual T.I.F. Curves

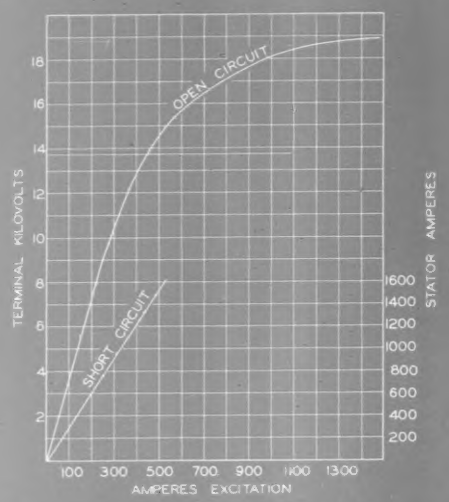


Fig. 3—Test Curves of Saturation and Impedence

spider arms and is free to expand without transferring stress to the spider. The torque between arms and rim is transmitted by means of axial keys fitting into notches in rim punchings and slots on the spider arm flanges.

These spider arms also support replaceable segmental brake rings on which the air brake acts when the machine is brought to, or held at, a standstill. The rotor poles, of standard construction, are dovetailed to the spider and carry copper damper windings, whose respective bars are silver-soldered into the pole end plates, forming a low resistance damper winding adequate to reinforce the generator stability and minimize voltage distortion during single-phase fault conditions.

The generator collector rings are located above the exciter, and the carefully supported field leads are carried through the shaft bore. The rotor field coils are securely supported on the rotor poles between bakelite duck washers. The insulation between turns is made up of combined mica and asbestos strips.

The output of slow-speed machines frequently is limited through field coil heating. To ease this limitation, the heat radiating surfaces of the generator fields have been greatly increased by winding with copper strip having a wedge shaped outer edge. Tests have proven that the effectiveness of this has made possible increased output per pound of active generator material.

The main and pilot exciter armatures are mounted on a separate spider bolted to main spider hub. Both the alternator and exciters are self-ventilated by means of radial type fans mounted on their respective spiders.

All rotor parts and bearings are proportioned to withstand duties incidental to the runaway speed of these water wheels, which in this case is 207 rpm.

Yoke sectionalized

The yoke is welded and made in four sections to facilitate shipment and erection. It holds the dovetailed silicon steel punchings, which are firmly clamped between segmental non-magnetic finger plates. The stator coil is of the double layer, multi-turn type, with one of the turns transposed in the stator core to reduce eddy currents. The coil insulation is Class "B" throughout. The coil ends, leads, and jumpers are firmly supported by means of insulated brackets. The ends and beginnings of all phases are brought out to permit installation of differential relay protection.

The generator ventilation is of the enclosed circulating type in which the rotor fan forces the ventilating air over the coil and core surfaces, through the yoke, to the water-cooled fin type air coolers, and to the enclosing housing, from which it is drawn back over the top of the stator into the rotor fans. There are eight surface air coolers located symmetrically around the stator frame.

The air housing contains the coolers, pipes, generator leads, etc., and allows space for their inspection. Access to the inside of the air housing is gained by means of a number of doors which have to be close-

Fig. 4—Open Circuit Terminal-to-Terminal Wave Form.

fitting, as the housing must be sufficiently tight to hold carbon dioxide when admitted to the ventilating system, for fire protection.

Each machine is provided with 10-ohm resistance type temperature detectors: 12 are located in generator winding, two in the shoes of each of the bearings, one in the discharge air from each cooler, and one in the exciter discharge.

The generator armature is designed with 4½ slots per pole or a total of 432 (slot size 1.05 in. by 7.75 in.). It is wound with six turn, double layer, diamond shaped coils which, to minimize eddy currents, have one turn transposed in the slot portion. The coils are connected in four circuit Y to reduce harmonics while the armature core is skewed to minimize magnetic operating noise. The stator core is axially subdivided by means of 16 rows of ⅜ in. ventilating openings. The rotor pole is of the dovetail construction, and the pole face has an enclosure of 78½ percent.

The guaranteed generator efficiencies at 90 percent power factor, including all generator and exciter losses, are 95.9, 96.5, 96.65, and 96.55 at loads of 15,000, 22,500, 30,000, and 34,500 kva respectively. The efficiency determined by deceleration tests after installation exceeded in all cases those guaranteed.

The values of balanced and residual TIF which were guaranteed not to exceed 50 and 30 respectively are shown in Fig. 2. From the generator test curves of no load saturation and synchronous impedance in Fig. 3, it may be seen that the generator short circuit ratio is 1.11 which is slightly better than the guaranteed value of 1.1.

The open circuit terminal-to-terminal wave form, which was guaranteed not to deviate by more than 10 percent from a true sine wave, is shown in Fig. 4 and was within 2 percent of a true sine.

In conclusion, a few dimensions and weights of the various generator parts may be of interest:

Stator bore diameter........................380 in.
Outside diameter of the air housing...........557 in.
Guide bearing dimensions.....84 in. dia x 14 in. long
Outside diameter of thrust bearing shoes......93 in.
Net stator weight without air housing......194,000 lb
Net rotor weight with alternator shaft.....579,500 lb
Capacity of the bearing oil container........2100 gals
Total rotor weight plus hydraulic water wheel thrust...............................2,050,000 lb
Air housing under upper bridge for exciter support weight...........................82,000 lb
Total machine weight...................1,200,000 lb

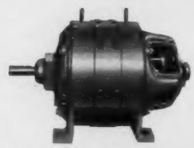
Correction

On page 32 of the June, 1941, Allis-Chalmers ELECTRICAL REVIEW, the three simultaneous equations should have been published as follows:

$$Z_K = \sqrt{(Z_1 - Z_3) Z_2}$$

$$Z_H = Z_1 - Z_K = Z_1 - \sqrt{(Z_1 - Z_3) Z_2}$$

$$Z_X = Z_2 - Z_K = Z_2 - \sqrt{(Z_1 - Z_3) Z_2}$$

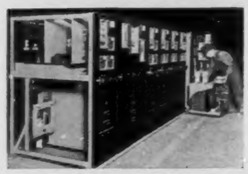


Regulator, Exciter in One Unit

Efficient, quick-response regulation for automatically holding constant output on d-c and a-c machines is available with the new "Regulex" exciter recently introduced.. This rotating regulator reduces the first cost of a generator or motor installation because exciter and regulator are combined in one unit. The Regulex consists of a differential amplifier for controlling the excitation on d-c motors and generators to give constant voltage, current, speed, or tension.

The Regulex was originally developed for steel mill use, principally for giving constant tension on winding and unwinding coils. It is now being applied to other steel mill drives and mine hoists. Regulex exciters are being developed for all sizes of d-c machines, and they are also applicable to a-c synchronous motors, generators, and condensers.

Metal-Clad Switchgear Takes Less Space



New midget metal-clad switchgear only slightly larger than an ordinary file case is now available with the standard ratings of 25,000 or 50,000 kva interrupting-capacity circuit breakers for a maximum service voltage of 5000 volts. The 600-800 and 1200 ampere units, only 20 inches wide by 64 inches high, are all standardized to simplify station layout planning. The 2000 ampere units are only slightly larger.

The switchgear units are complete in every detail and utilize standard vertical lift circuit breakers. The stationary portion, consisting of bus bars, disconnects, grounded compartments for current and potential transformers and instrument panel mounted on the front door, is all supported on a welded steel framework. The circuit breaker, primary disconnect fingers, auxiliary switches and secondary disconnects are all mounted on a removable vertical lift unit for easy servicing.

A special design of breaker lifting mechanism, together with an ingenious arrangement of parts, makes possible this compact unit that still maintains accessibility.

For further, more detailed information regarding these new products, write the Editors of ELECTRICAL REVIEW.

ORDER OUT OF CHAOS

From a maze of concrete and scaffolding emerged the efficient simplicity of Chickamauga Dam's generator floor. A pioneer example of the field erection of hydro-electric equipment illustrates the problems of coordination and procedure involved in bringing this order out of chaos.

H. A. Wallace

SERVICE AND ERECTION DEPARTMENT • ALLIS-CHALMERS MANUFACTURING COMPANY

● Chickamauga Dam is one of the outstanding hydro-electric projects of the Tennessee Valley Authority. This man-made impediment to the river's natural flow is located on the Tennessee River about eight miles above the city of Chattanooga. In operation since early 1940, it backs up the Tennessee River, forming the Chickamauga Reservoir, which extends approximately 50 miles upstream to Watts Bar Dam, another T. V. A. project.

The installation of the heavy equipment in the Chickamauga Dam powerhouse was a typical hydro-electric erection job. Its many problems were solved chiefly through the coordination of the efforts of many men engaged simultaneously in varying types of work, each doing his small bit toward the completion of the finished structure.

The initial installation included three waterwheel-driven alternating-current generators, together with the necessary auxiliary equipment — oil circuit breakers, transformers, switchboards, pumps, etc. This article deals exclusively with the field erection of the three main generators.

The generators

Each generator is of the vertical, "umbrella" type with a capacity of 30,000 kva at 90 percent power factor and generated voltage of 13,800 volts. The rated three-phase, 60-cycle, a-c output is 1255 amp at a speed of 75 rpm.

These generators are quite unusual from an engineering viewpoint — they are among the largest generators, physically, that have ever been installed; they are of welded fabricated construction and of such large dimensions that shop assembly was impractical. Consequently, the machines were not only assembled, but also completely wound in the power station.

AT LEFT: Fig. 1 — From this maze of concrete and scaffolding, on the day erection was started on the generators, finally emerged the complete Chickamauga Dam powerhouse (Fig. 15).

An interesting contrast can be observed by comparing Figs. 1 and 15. Fig. 1 shows the condition of the powerhouse and status of construction the day that erection of the generators was started, and Fig. 15 shows the finished powerhouse with all the equipment in commercial service.

The individual parts were shipped by rail to the dam site and unloaded from the cars with an 80 ton gantry crane (Fig. 2), lowered through a hatchway onto the generator floor, and thereafter handled by means of the 275 ton powerhouse crane. Once the individual pieces were placed on the generator floor, they became a part of the scheme of erection procedure. In general, this procedure may be divided into the following five categories:

1. Unloading and cleaning
2. Unit assembling
3. Placing, aligning, and grouting
4. Testing and checking
5. Preliminary operation

Sometimes the unloading and transferring of heavy equipment in the field presents a serious problem because of the deficiency of lifting equipment of the proper capacities. However, this particular job carried no such problems because, as explained above, excellent lifting facilities had been provided.

The cleaning of equipment does not usually present any problem that a lot of hard and tedious work cannot solve. Every piece of equipment which had machined surfaces was carefully protected against corrosion and physical damage by means of heavy grease and padded wrapping before it left the factory. All this had to be removed by means of solvents, scrapers, and rags before any further work could be done. After cleaning, the individual pieces were checked for damage, and any small nicks or scratches removed by filing and stoning. The pieces were then ready for assembly.

Unit assembling

The assembly of various integral parts of the generator into units was one of the more important phases

of the work. The placing of embedded parts of the hydraulic turbine had to be done before there could be any foundation on which to set the stator. Even after the stator had been located on its foundation and the winding started, the turbine erection still had to be considered because the remaining parts of the turbine had to be handled through the stator opening. In other words, even though the turbine and generator were furnished by different manufacturers, the erecting engineers in charge of the respective machines had to work hand in hand in order that both units could be assembled at the same time, in a limited space, and placed finally so that they would operate perfectly together.

Unit assembly of the integral parts of the finished machine was governed by several factors; i. e., storage space, assembly space, status of assembly of other parts, and progress of assembly of the complete machine. Fig. 3 illustrates this problem. In the lower left-hand corner can be seen part of the assembled rotor. An assembly pedestal was provided in this corner of the powerhouse, and all three rotors were completely stacked and assembled in this space, one at a time, and from there transferred when needed to the final position inside their respective generators.

The stator yokes were each assembled on their respective foundations and the winding begun. One stator yoke without any coils can be seen located on its foundation in the foreground of Fig. 3. In the right center of the figure is the upright main shaft; beside it is the start of the assembly of the bearing bracket, and just beyond is another stator yoke during the winding process. At the extreme end of the powerhouse is the first completed machine which was already in operation. This picture also illustrates the staggered erection schedule, limited storage space, and the confined conditions under which erection had to be carried on at times.

The three large integral units of each generator, assembled in different parts of the powerhouse and later transferred to their final location, were the stator, the rotor, and the main bearing support. In order to provide shipping clearances the stator yoke was sectionalized into quarters.

The handling of the stator yoke

The laminations were stacked in the factory. Each section of the yoke weighed about 22 tons. After the individual sections were landed on the generator floor, the first operation after cleaning was to bolt the sections together and form the complete yoke. This was done on the final stator foundation. A scaffold for the winders was then built inside the yoke with care taken that the scaffold did not project over the turbine pit. At this stage of erection many of the large turbine parts were still to be lowered into place through the center of the stator. The scaffold was built in sections so that it could be removed and used on the next machine.

The stator coils were shipped from the factory in boxes. Before the individual coils were placed in the slots, they were heated with direct current by means of an electric welding machine. After the coils had been placed in the slots, each coil was subjected to a high potential test which served as a check against

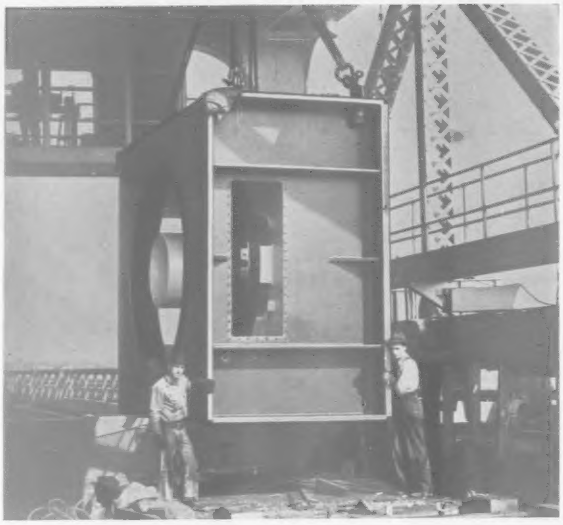


Fig. 2 — The 80 ton gantry crane unloads the central section of the bearing housing from freight car prior to lowering it to a hatchway onto the generator floor.

injury either in shipping or installing. Fig. 6 shows the assembled yoke with some of the stator coils installed, and the location of the winders' scaffold. An interesting use of tarpaulins is shown in this picture. These were necessary for protective purposes because at this stage of erection the powerhouse roof had not been completed, another indication of the conditions under which the erecting work functioned. On completion, the stator winding was dried out and subjected to a 28,600 volt puncture test for one minute in accordance with A. S. A. standards C-50.

The building of the rotor started with the placing of the hub on an assembly pedestal (Fig. 4) constructed especially for this purpose and mounted on a steel foundation plate concreted into the main generator floor. The 16 fabricated arms were then assembled on the hub. The next operation was the stacking of the rotor punchings (Fig. 7) which formed the laminated rotor rim. After the punchings had been pulled down, the 96 rotor poles were hung in place. The expanding of the rim, placing the keys, and assembling of the fan completed the construction of the rotor. The finished unit weighing approximately 225 tons is shown in Fig. 5.

The main bearing bracket

The last large unit assembly was the main bearing bracket or support. The generator shaft was set up on end on a steel foundation plate provided for the purpose. The supporting arms were bolted to the oil pot or center piece, and the entire assembly was lifted over the shaft. It was then supported on cribbing at approximately the same elevation relative to the shaft as it would be in actual operation (Fig. 8). The thrust bearing, a standard eight-shoe Kingsbury, was assembled complete with the thrust collar, runner, etc., and adjusted. The entire assembly was then picked up and placed on its final foundation inside and below the stator elevation, as shown in Fig. 9.

Fig. 3—The Three Generators in Varied Stages of Erection.

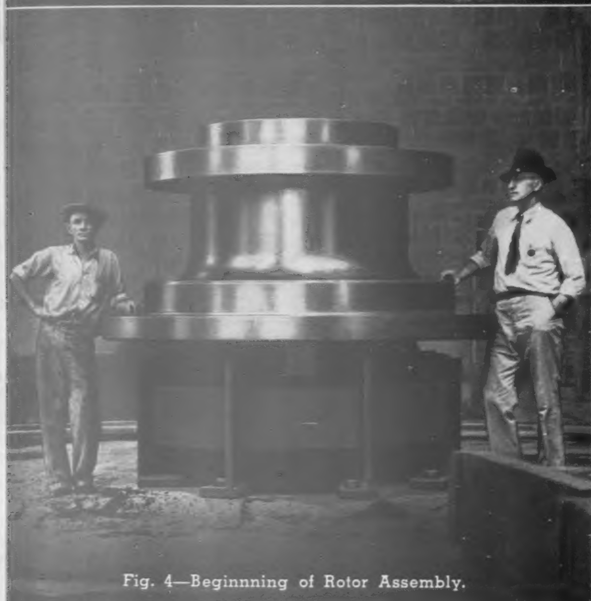


Fig. 4—Beginnning of Rotor Assembly.

Fig. 5—Completed Rotor Weighs about 225 Tons.

Fig. 6—Assembled Yoke during Winding.

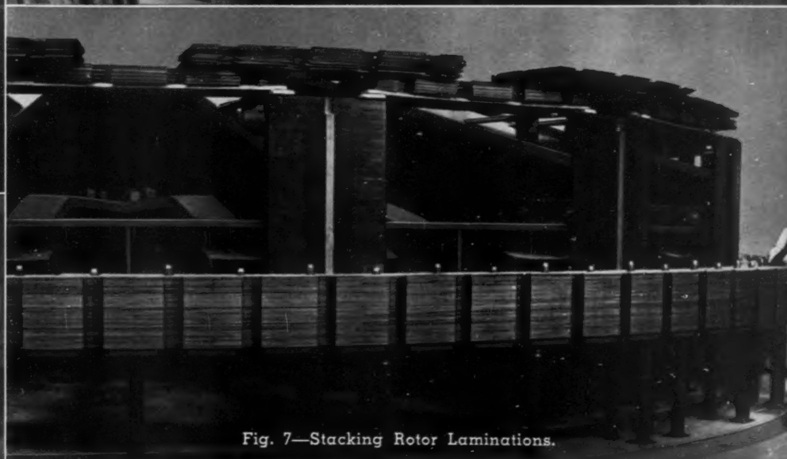


Fig. 7—Stacking Rotor Laminations.

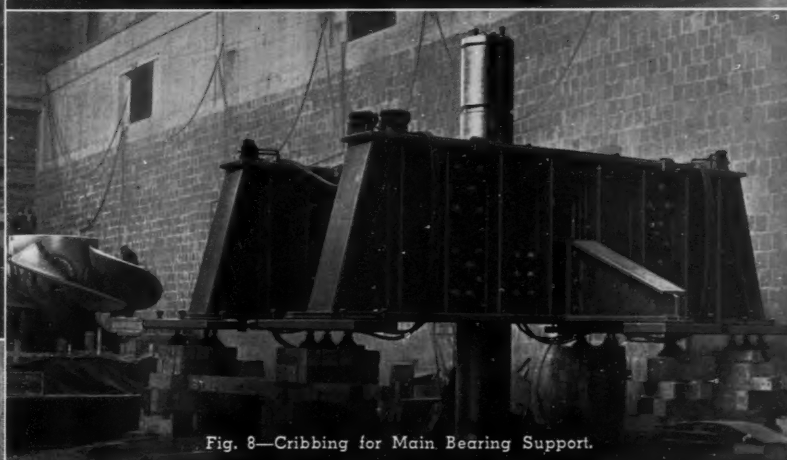


Fig. 8—Cribbing for Main Bearing Support.

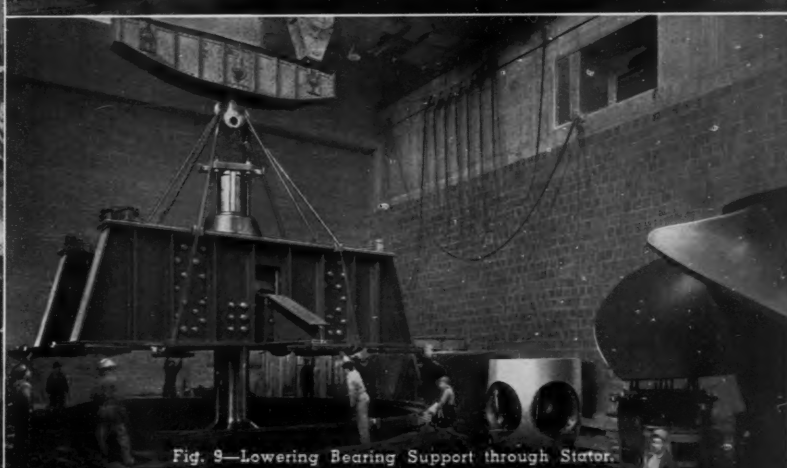


Fig. 9—Lowering Bearing Support through Stator.

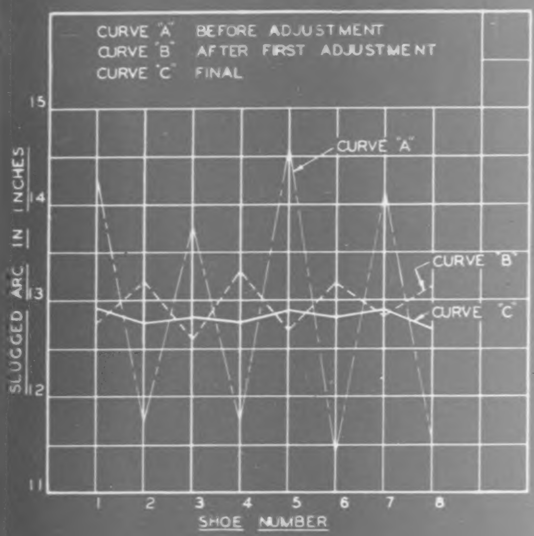


Fig. 10—Typical Adjustment Chart of "Slugged Arc" Method of Equalizing Load on Bearing Shoes.

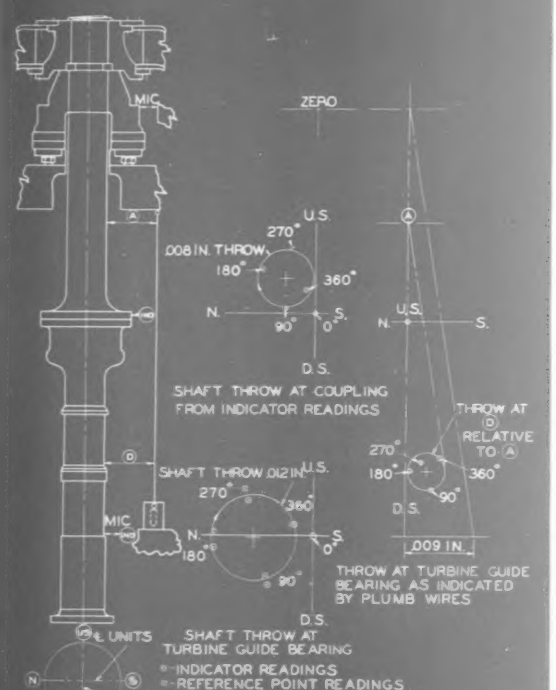


Fig. 11—Results of a Shaft Rotation Check.

An unusual and interesting procedure was followed in adjusting the thrust bearing to equalize the load on the individual shoes. Instead of using the conventional method of tightening and adjusting screws by "feel," a much more consistent and dependable method based on "slugged arc" was used. The "slugged arc" is the length of arc the wrench travels through from "hand tight" to "slug tight" obtained by using a sledge hammer. If the screws are adjusted so that the "slugged arc" for all shoes is equal, within reasonable limits, the loading of all shoes will be uniform.

Figure 10 shows a typical adjusting chart. Curve "A" shows the distribution of load (variation in "slugged arc") when the shoes were tightened by "feel." Curve "B" shows the change in loading after one adjustment by the "slugged arc" method, and Curve "C," the uniformity of load on the shoes after the final adjustment. The final result should be obtained in two or not more than three adjustments. This was the procedure followed at Chickamauga. The load on these thrust bearings under operating conditions is approximately 2,000,000 pounds, making it self-evident that the load on the individual shoes should be uniformly distributed.

After the bearing bracket had been lined and leveled, the sole-plates were grouted in with non-shrinking cement grout. The hydraulic turbine shaft and runner were then raised, and the coupling was made up. Instead of using temporary bolts and sledge hammer tactics, the shaft and runner were raised by means of five 50-ton jacks and strongbacks as shown in Fig. 12. This is a much faster and safer method, and at no time were the coupling faces more than 0.003 in. out of parallel.

The coupling bolts, which had 0.001 in. press fit, were shrunk by cooling with dry ice and dropped into place. After the bolts had warmed up to ambient temperature, they were all equally stressed by stretching 0.010 in.

Alignment

In the last two or three years there has been a great deal of activity concerning the subject of shaft alignment. Many opinions have been voiced on this subject, and some very exacting demands have been made at various times. The controversy resolves into the question of just how true the combined shafts of a large hydro-electric generating unit can be made to rotate. There are definite, practical machining tolerances which cannot be economically surpassed. This means that there are very definite limits of accuracy which can be obtained in machining these large turbine and generator parts. To answer the previous question, it must be decided just how much shaft throw can reasonably be expected under existing limits of machine accuracy. This is a problem governed largely by the size of the generating units and a logical analysis of the factor concerned. The method used and results obtained in checking shaft throw on the Chickamauga installation were as follows:

After the turbine and generator shafts were coupled together and the generator rotor had been placed in position (Fig. 13), a shaft rotation check was made. This check consisted of removing the turbine and

generator guide bearings so that the combined shaft hung freely suspended on the thrust bearing and taking measurements by means of plumb wires, micrometers, reference points, and dial indicators in order to establish the initial fixed position of the shaft. The shaft was then rotated 90° and the same measurements taken. This operation was repeated at 180°, 270°, and 360°. If all the readings were correct, the shaft would come back to the same relative position at 360° as it was at 0°. In the event that the combined shaft was not perfectly straight, the center of the shaft at the bottom would describe the path of a circle. The diameter of this circle represented the shaft throw. Fig. 11 shows the results of a typical shaft rotation check on one of the Chickamauga hydro-electric units.

After the combined shaft had been proved free of any "kinks" or misalignment, the deck structure was assembled. This structure is a network of beams which supports the main and pilot exciter fields and the Kaplan head (part of the turbine). When this network of beams was covered with steel deck plates, it served as a support for the outer air housing. Fig. 14 shows the deck structure and outer air housing in the process of assembly.

The ventilating and cooling system of these generators is self-contained. This means that the air inside the generator is not changed but is continuously relieved of its thermal content by being passed through air coolers inside the housing.

Preliminary operation

The preliminary operation of these units was similar to the standard practice which has been used for years with this type of equipment. The machines were started up and run at about 75 percent normal speed until the bearings could be checked and their temperature approached a steady state. The unit was then brought up to normal speed and held there while it was checked for balance, vibration, and temperatures. This preliminary mechanical test run took about five or six hours. After the unit was shut down and short circuited for the dry-out run, the machine was started again, brought to normal speed and held there. The temperature of the stator winding was brought up to dry-out standard and maintained, and resistance readings were taken at regular intervals. When the resistance readings became constant, indicating the winding was dry, a final high potential test of 75 percent of the full A. S. A. standard, or 21,400 volts, was made on the stator winding for one minute, one phase at a time. After a 5,000 volt puncture test on the rotor, a check for phase rotation, and adjustment of the voltage regulator, the generator was put into commercial operation.

All these generators have been tested and accepted and have been in commercial operation since early 1940.

As stated before, this was a typical field erection job of a hydro-electric unit. It had its problems, and, as is usually the case, they were all solved. But there is one thing rather outstanding about so large a job as this one — a thing of which the writer is quite proud. There was not a single lost-time accident during the entire field erection of these generators, and for a considerable period of time the crew included over 40 men engaged in this work.

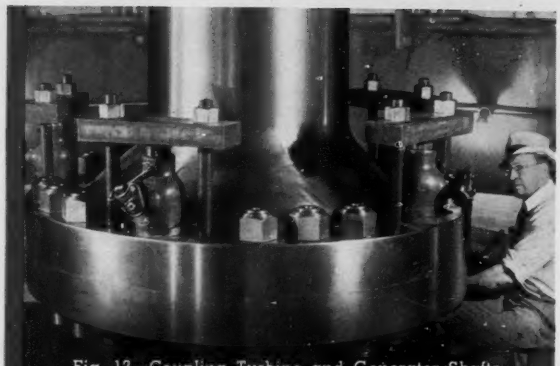


Fig. 12—Coupling Turbine and Generator Shafts.

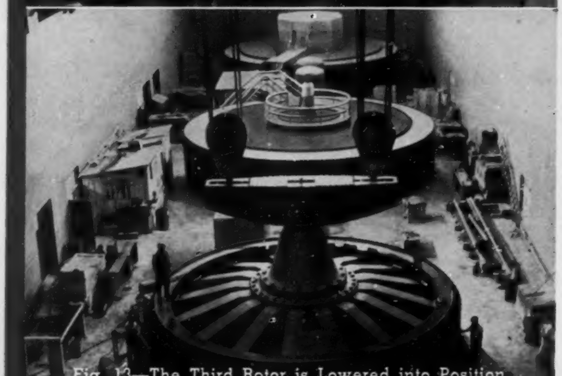


Fig. 13—The Third Rotor is Lowered into Position.

Fig. 14—Outer Air Housing Assembly.

Fig. 15—The Completed Generator Floor.

MATHEMATICAL PRODUCTION TOOLS

With Defense demanding increased production all down the line, any time-saving device is welcomed by industry. That's why alignment charts . . . as helpful in their field as the slide rule and computing machine are in theirs . . . now find widespread use.

W. C. Sealey, **Engineer-in-Charge, Transformer Design**

ELECTRICAL DEPARTMENT • ALLIS-CHALMERS MANUFACTURING COMPANY

● When an engineering problem involves three variables, alignment charts may aid in securing a rapid solution. A common form of alignment chart has three scales, one for each variable. If a straight line is drawn through the points representing the values of two of the variables, the value of the third variable is indicated at the intersection of the straight line with the third scale.

Simple charts

The most common form of alignment chart has three parallel straight lines, one for each variable. Each straight line is divided into scale divisions for its variable. Such a chart is shown in Fig. 1. Whenever an equation can be reduced to a form so that the sum of three terms, each containing only one variable, equals zero, an alignment chart with three parallel scales can be constructed to represent the relation between the three variables.

Such an equation can always be changed to such a form that the sum of the coefficients of the variables is equal to zero, or, stated another way, to a form such that the coefficient of the second term is equal to the negative of the sum of the coefficients of the first and third terms. The general form of such an equation after transformation is

$$(1)\quad mr-(m+n)\,s+nt=0.$$

This equation expresses the relation between the three variables R, S, and T when

r is a function of R only,

s is a function of S only,

t is a function of T only, and

m and n are constants.

When plotted on rectangular coordinates with axes X and Y (where x and y are distances parallel to the X and Y axes respectively), the line for the scale of R is located at a distance of $-n$ from the Y axis (at $x=-n$). The line for the scale of S is on the Y axis (at $x=0$), and the line for the scale of T is at a distance of $+m$ from the Y axis (at $x=+m$).

Each value marked on the R scale is the value of R corresponding to a distance r from the X axis ($y=r$).

Each value marked on the S scale is the value of S corresponding to a distance s from the X axis ($y=s$).

Each value marked on the T scale is the value of T corresponding to a distance t from the X axis ($y=t$).

An example will indicate the procedure to be followed.

EXAMPLE: Required to make an alignment chart for the equation

$$8\cos S+3\log T+4=-R$$

with variables of R, S, and T.

SOLUTION:

$$(R+4)+8\cos S+3\log T=0$$

$$(1)\quad (R+4)-4\,(-2\cos S)+3\,(\log T)=0$$

by making the sum of coefficients equal to zero by changing the coefficient of the second term so that it is equal to the negative of the sum of the other two terms.

In this equation the following are the values corresponding to equation (1): $(mr-(m+n)s+nt=0)$: $m=1$; $n=3$; $r=(R+4)$; $s=(-2\cos S)$; $t=\log T$. The scale of R would be plotted on a straight line 3 units to the left of the Y axis; values of $y=(R+4)$ would be plotted on this line, and the points would be numbered with the corresponding values of R. The scale of S would be the Y axis; values of $y=(-2\cos S)$ would be plotted on this line, and the points would be numbered with the corresponding values of S.

The scale of T would be a straight line one unit to the right of the Y axis; values of $y=\log T$ would be plotted on this line, and the points would be numbered with the corresponding values of T.

This example illustrates the general principles to be followed. In practice, refinements are introduced in order to obtain the desired length and location of the scales.

The following specific rules give the detailed procedure for convenience in construction in actual prac-

tice. An explanation of the individual rules is given in the accompanying example.

Constructing an alignment chart with parallel straight scales

The following detailed procedure may be followed to construct an alignment chart with parallel straight scales:

1 The equation to be used is written down in its original form.

2 This equation is reduced to a form so that the sum of three terms, each containing only one variable quantity, equals zero. The equation is rewritten if necessary so that the signs of the coefficients of the first and third terms of the equation are the same.

3 The values of y for the first and third terms of the equation should be calculated for the extreme values of the variables for which the chart is to be used. (For each variable, y=the part of the term containing that variable.) The length of a scale is the difference between extreme values of y.

4 The scale length for the first and third terms should be made approximately equal by multiplying the variable part of either the first or the third term of the equation by a suitable factor (and dividing the coefficient of the term by the same number).

For term No. 3, this factor is equal to (the difference between the extreme values of y for term No. 1) ÷ (the difference between the extreme values of y for term No. 3). It may also be determined by inspection, since only an approximate value is required.

5 To make the bottom of the outer scales begin at the same distance from the X axis, a suitable number is added to the variable part of the third term and subtracted from the variable part of the first term of the equation. This suitable number is equal to (the difference between the lowest value of y for term No. 1 and the lowest value of y for term No. 3) × (the product of the coefficients of these terms) ÷ (the sum of the coefficients of these terms). It may also be determined by inspection, since only an approximate value is required.

6 The coefficient of the second term of the equation is made exactly equal to the negative of the sum of the coefficients of the first and third terms by multiplying the coefficient of the second term by a suitable factor and dividing the variable portion of the second term by the same number. This factor is equal to (−1) × the (sum of the coefficients of the first and third terms) ÷ (the coefficient of the second term).

7 Values of y for the three variables are calculated and tabulated for the range desired.

8 From an inspection of these values, suitable scales for x and y are chosen. The first term scale is placed at x=the negative of the coefficient of the third term. The second term scale is placed at x=0; the third term scale is placed at x=the coefficient of the first term.

9 The tabulated values of y are plotted on the respective vertical lines, and the plotted points are numbered with the corresponding values of the variable for each scale. Intermediate points are determined graphically or by calculation.

An example of the use of these specific rules follows. (The numbers correspond to the numbers of the rules which they illustrate.)

EXAMPLE: Required to construct an alignment chart for the equation:

1. $$B=\frac{34.9\times10^5\times E}{f\,A}=\frac{58200\,E}{A}$$

where B=flux density which varies from 6000 to 18000 gausses

E=volts per turn which varies from 5 to 100 volts per turn

A=Area which varies from 30 to 1000 sq in.

f =cycles per second=60.

2. To reduce the equation to the specified form, the log of each side of the equation is taken:

$\log B=\log 58200+\log E-\log A$

and the terms are rearranged as follows:

$(\log B-4.765)-\log E+\log A=0.$

3. Extreme values of y for the first and third terms of the equation are calculated and tabulated below:

For first term, $y=\log B-4.765$.

For third term, $y=\log A$.

B	y	A	y
18000	−.510	1000	3.000
6000	−.987	30	1.477
Scale length	.477	Scale length	1.523

4. Scale A can be made the same length as scale B by multiplying the variable part of the third term by $\frac{.477}{1.523}=.313=$approximately ⅓.

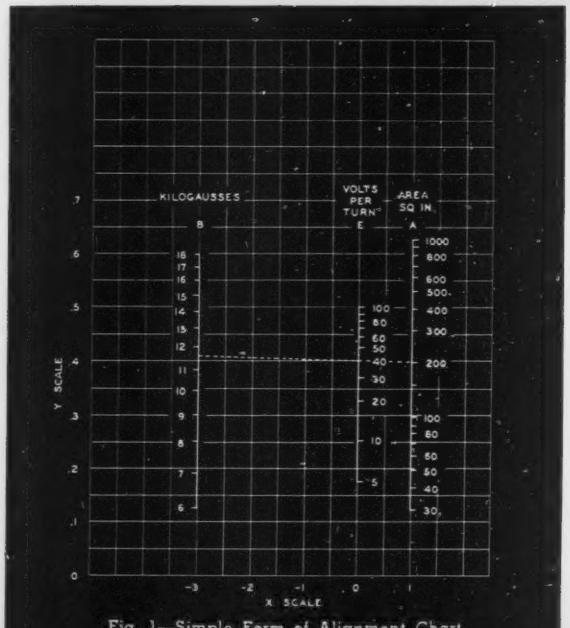


Fig. 1—Simple Form of Alignment Chart.

The equation then has the form:

$(\log B - 4.765) - \log E + 3\,(\tfrac{1}{3}\log A) = 0.$

5. The bottom of the scale of B now is at $y = -.987$; the bottom of the scale of A is at $y = .492$. The suitable number is equal to $(-.987 - .492)\left(\frac{1\times 3}{1+3}\right)$ $= -1.11$ (approximately). If the number -1.11 is added to the third term and subtracted from the first term, the equation then has the form

$(\log B - 3.654) - \log E + 3\,(\tfrac{1}{3}\log A - .37) = 0,$

and the bottom of the scale of B (for $B = 6000$) will be at $y = .122$, and the bottom of the scale of A (for $A = 30$) will be at $y = .123$.

6. The coefficient of the second term is made equal to the negative of the sum of the coefficients of the other terms by using the factor $\left(\frac{1+3}{-1}\right)$ which is equal to 4, and the equation becomes

$(\log B - 3.654) - 4\,(\tfrac{1}{4}\log E) + 3\,(\tfrac{1}{3}\log A - .37) = 0.$

The equation is now in its final form.

7. Values of y are calculated and tabulated for the three variables as follows:

$y = \log B - 3.654$		$y = \frac{1}{4}\log E$		$y = \frac{1}{3}(\log A - .37)$	
B	y	E	y	A	y
18000	.601	100	.500	1000	.630
17000	.576	90	.489	900	.615
16000	.550	80	.476	800	.598
15000	.522	70	.461	700	.578
14000	.492	60	.445	600	.556
13000	.460	50	.425	500	.530
12000	.426	40	.400	400	.497
11000	.387	30	.369	300	.456
10000	.346	20	.325	200	.397
9000	.300	10	.250	150	.355
8000	.250	5	.175	100	.297
7000	.191			90	.281
6000	.124			80	.264
				70	.245
				60	.223
				50	.196
				40	.164
				30	.122

8. Scales are chosen for x and for y independently in order to secure a chart of the desired size. The chart of Fig. 1 is plotted with the scale of B placed at $x = -3$, the scale of E placed at $x = 0$, and the scale of A placed at $x = 1$.

9. The tabulated values of y are used to locate the scale points of A, B, and E. Intermediate points are determined graphically.

To use the completed chart, if any two variables are known, the value of the third variable may be determined by placing a straight edge or drawing a straight line through the two points representing the two known variables, each on its own scale. The intersection of the straight line with the scale of the unknown will indicate the value of the unknown quantity. The dotted line of Fig. 1 indicates a typical example.

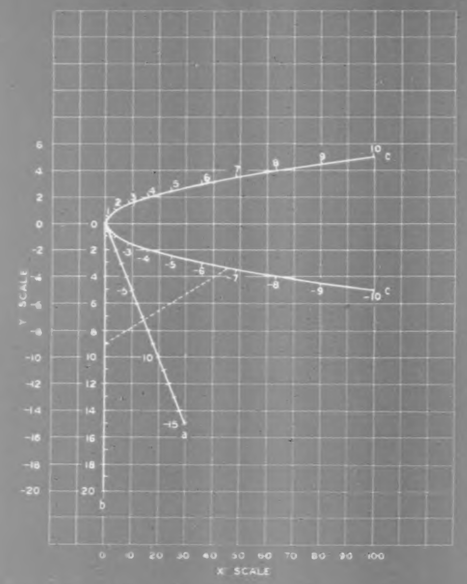


Fig. 2—Complex Form of Alignment Chart.

Complex charts

While charts with parallel straight scales are the simplest and consequently the most commonly used, certain equations cannot be expressed by such charts since it is impossible to put them into the required form. In such cases it may be possible to use a more general form of chart with non-parallel or curved scales, such as that of Fig. 2.

If it is desired to represent an equation with three variables—A, B, and C respectively—by an alignment chart, such a chart can be constructed if it is possible to transform the equation to the following form:

(2) $(t_1 - s_1)r + (r_1 - t_1)s + (s_1 - r_1)t = 0$

where r and r_1 are functions of R only

s and s_1 are functions of S only

t and t_1 are functions of T only.

If the three curves given below are plotted on rectangular coordinates with axes X and Y and the individual points on the curves are numbered with the values of R, S, and T used to determine the respective values of x and y, an alignment chart representing the relations among these variables is thereby obtained.

The equations are:

For curve of R: $x = r_1$, $y = r$

For curve of S: $x = s_1$, $y = s$

For curve of T: $x = t_2$, $y = t$

If $t_1 - s_1 = m$, and $s_1 - r_1 = n$, equation (2) reduces to the form

$mr - (m+n)s + nt = 0$

which is exactly the same as equation (1).

To construct a chart for an equation of the general form of equation (2), the procedure is similar to that outlined for the simple form of equation (1). However, because of the wide possibilities of variation of form of the general chart, less specific rules are given.

Constructing an alignment chart of general form

1 The equation to be used is written down in its original form.

2 This equation is reduced to the form of equation (2), namely

$$(t_1-s_1)r+(r_1-t_1)s+(s_1-r_1)t=0.$$

(Note that if the quantities in parentheses are considered to be coefficients, the sum of the coefficients is equal to zero.)

3 Values of r_1, s_1, and t_1 are chosen, starting with the coefficient containing the greater number of variables and proceeding to the other coefficients.

4 A few values of x and y are calculated for each curve for the range in values desired for each variable, using the relations:

For curve of R: $x=r_1$, $y=r$

For curve of S: $x=s_1$, $y=s$

For curve of T: $x=t_1$, $y=t$

5 From an inspecton of these values, suitable scales for x and for y are chosen and the tabulated values of x and y are plotted, marking each point with the corresponding value of R, S, or T. Additional points as desired are calculated or determined graphically.

EXAMPLE: (The numbers of this example correspond to the numbers of the rules for construction.)

1. Given the equation $ac^2+2ab+bc^2+ac=0$ and required to construct an alignment chart with the three variables a, b, and c, where the value of a varies from 0 to −15, b varies from 0 to 20, and c varies from −10 to +10.

2. By inspection and trial and error, the terms may be grouped to form the following equation:

$$(c^2)a+(c^2+2a)b+(a)c=0.$$

It is evident that by using the proper factors for the various terms, the sum of the coefficients can be made equal to zero as follows:

In its present form, the sum of the coefficients is equal to

$$c^2+c^2+2a+a=2c^2+3a.$$

By inspection, the equation can be transformed to

$$(c^2)a+(-c^2-2a)(-b)+(2a)\frac{c}{2}=0$$

in which it will be noted that the sum of the coefficients is equal to zero; viz., $c^2-c^2-2a+2a=0$.

The form of the equation $(c^2)a+(-c^2-2a)(-b)+(2a)\frac{c}{2}=0$, is that of $(t_1-s_1)r+(r_1-t_1)s+(s_1-r_1)t=0$.

3. Comparing these two equations, by inspection we let

$a=r=$ a function of $R=$ a function of a; $a=R$

$-b=s=$ a function of $S=$ a function of b; $b=S$

$\frac{c}{2}=t=$ a function of $T=$ a function of c; $c=T$.

The coefficient of $(-b)$ contains the greater number of variables, and the portion of this coefficient which is a function of c is $-c^2$.

Consequently, $c^2=t_1$ and $-2a=r_1$.

By inspection of the coefficient of $\frac{c}{2}$, the relation $s_1=0$ is obtained.

4. Accordingly, from rule 4,

For curve of a: $x=-2a$, $y=a$

For curve of b: $x=0$, $y=-b$

For curve of c: $x=c^2$, $y=\frac{c}{2}$

Using these relations, the following tabulation is obtained:

a	$x=-2a$	$y=a$
0	0	0
−10	20	−10
−15	30	−15

b	$x=0$	$y=-b$
0	0	0
10	0	−10
20	0	−20

c	$x=c^2$	$y=\frac{c}{2}$
0	0	0
2	4	1
4	16	2
6	36	3
8	64	4
10	100	5
− 2	4	−1
− 4	16	−2
− 6	36	−3
− 8	64	−4
−10	100	−5

5. From an inspection of these values, the scales for x and y shown in Fig. 2 are chosen. The curves are plotted, and the plotted points marked with values of a, b, and c from the tabulation to obtain the completed chart of Fig. 2. By placing a straight edge on this chart, as indicated by the dotted line, the value of the third variable may be obtained when the values of the other two are known.

By following the procedure outlined, an alignment chart may be constructed for any equation which can be put into the specified form. It is impossible to put some equations in the specified form, but even for these a modification of the variables may make a useful chart of this type possible.

ON FOLLOWING PAGES: Stretching across the Tennessee River about eight miles above Chattanooga is T. V. A.'s Chickamauga Dam.

THE GAS TURBINE

I. SOME 2,000 YEARS AFTER HERO*

From "imparting motion to symbolic figures on an altar" in 130 B.C., to modern usage in gasoline cracking plants, the combustion gas turbine has had an eventful history. Today, because of the absence of complex auxiliaries and because of the universal presence of its working medium—air, the gas turbine is becoming increasingly important.

Dr. J. T. Rettaliata

STEAM TURBINE DEPARTMENT • ALLIS-CHALMERS MANUFACTURING COMPANY

● Few, if any, other mechanisms have had as much time and effort devoted to their development, and with such limited success, as the gas turbine prior to the present combustion type. Apparently misled by its ostensible simplicity, innumerable inventors have experienced repeated failures in their attempts to achieve a successful gas turbine. It is logical to inquire why a practical design was not evolved during these many years of experimentation.

Referring particularly to the combustion gas turbine, the only type to attain commercial significance up to the present time, the main obstacles confronting the early investigators were twofold — first, the inability of the then existent materials to withstand the high temperatures necessary to produce suitable cycle efficiencies; and, second, the lack of a compressor of adequate efficiency to make the cycle feasible. Metallurgical and aerodynamical advances have overcome both of these difficulties. The superior materials available today permit the utilization of elevated temperatures, and progress in fluid flow research has resulted in a highly efficient axial compressor.

The current increase in publicity concerning the combustion gas turbine, both in this country and abroad, may have created the impression that it is an invention of recent origin. To dispel such an erroneous conception, the following section, dealing briefly with the general background of the gas turbine, will serve to demonstrate the antiquity associated with the art.

Earliest history

The first device that could be included in the category of gas turbines was devised by Hero[1,4] of Alexandria in 130 B. C. The purpose of the machine was to impart motion to symbolic figures on an altar (Fig. 1). The heating of air in a vertical tube induced air in several radially displaced tubes, and rotation resulted from the creation of an impulse effect.

Fig. 1 — Hero's Gas Turbine, 130 B. C.

Although the date of its origin is obscure, the windmill may be considered as a gas turbine. The principle of the medieval "Smokejack"[2,5] was practically identical to that of the windmill, thus leading to the belief that its inventor may have received inspiration from the latter. The smokejack was placed in a chimney and rotation induced by the passage of flue gases through the bladed wheel (Fig. 2). While of questionable utility, it was claimed that it performed certain limited functions.

* This is the first of three definitive articles by Dr. Rettaliata on the history and modern status of the combustion gas turbine. Parts II and III will appear in the following issues of Allis-Chalmers ELECTRICAL REVIEW.

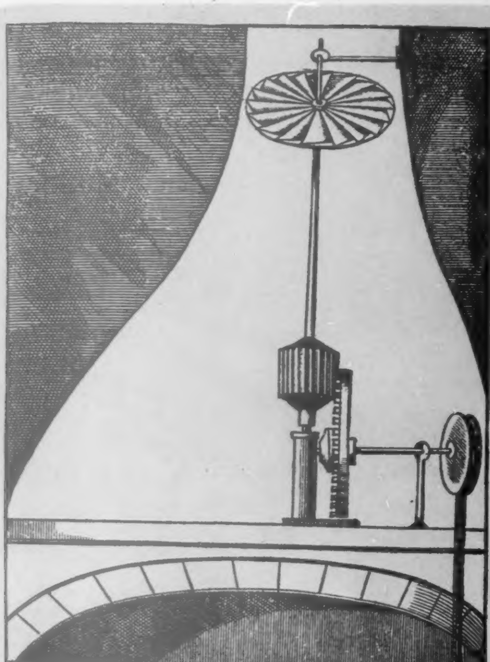


Fig. 2 — The "Smokejack," 17th Century.

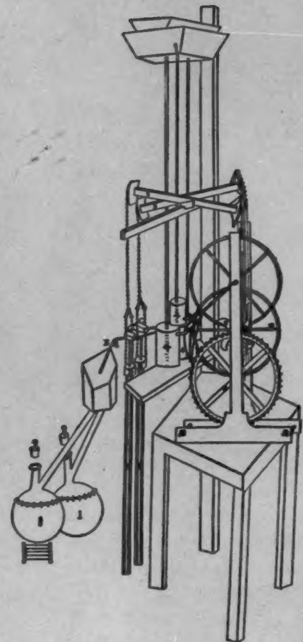


Fig. 3 — Barber's Gas Turbine, 1791.

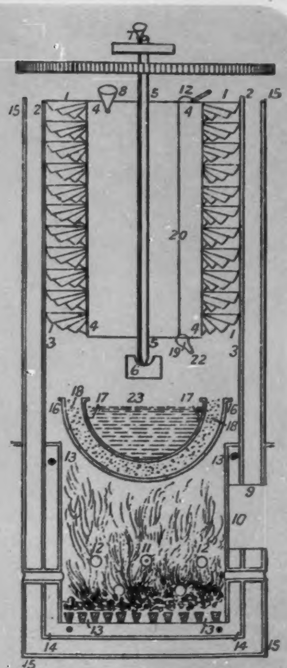


Fig. 4 — Dumbell's "Explosion" Type, 1808.

Many other references to various contrivances which may be classified as gas turbines are revealed by a survey of old literature. In 1791 John Barber[3], of England, obtained a patent on the first machine to bear an intrinsic resemblance to the modern combustion gas turbine. Although primitive in form, it comprised all of the essential features of a present day unit. Barber's patent drawings (Fig. 3) show compressors for both air and gas, a combustion chamber for burning the air and gas mixture, and an impulse type turbine wheel on which impinged the high velocity jet of gases leaving the nozzle in one extremity of the combustion chamber. To prevent the subjection of the turbine parts to excessive temperatures, a provision for cooling the gases by water injection was also indicated.

John Dumbell[4], also of England, patented in 1808 a device which was a prototype of the "explosion" type of gas turbine to be described more fully later (Fig. 4). Products of combustion traversed a turbine rotor comprising several rows of blading. The design could hardly be considered propitious, however, since it consisted entirely of rotating blading and did not include stationary or guide elements, thereby depriving it of the advantages of the present day multi-stage type of turbine.

A machine whose essential features resembled those of a turbine used in the Armengaud and Lemale experiments, to be recounted later, was patented by Bresson[4] in Paris in 1837. A fan delivered air under pressure to a combustion chamber where it mixed with gaseous fuel, burned, and the products of combustion, cooled by excess air, directed in the form of a jet onto a wheel.

Forerunners of present types

Other gas turbine schemes were proposed during this period, but they, as well as those mentioned above, exhibited various features of design which rendered them impracticable. In 1872, however, a patent for a "fire turbine" was applied for by Dr. F. Stolze[5], of Charlottenburg. The similarity between the Stolze gas turbine and the modern combustion type is indeed striking. The unit consisted of an axial flow compressor directly coupled to a reaction turbine (Fig. 5). Before expansion through the turbine, air discharged from the compressor was heated in an externally fired chamber. Tests on an actual unit indicated the design was unsuccessful primarily because of the inadequacy of the axial compressor. In view of the limited knowledge of aerodynamics existing at that time, such unfavorable results could be expected.

In 1884 Sir Charles Parsons[6] obtained his original steam turbine patent, and in it reference was made to the gas turbine. It was explained that the turbine could be converted into a compressor by driving it in a reverse direction by an external means (Fig. 6). The compressed air was discharged into a furnace where fuel was injected, and the resulting products of combustion were expanded through a turbine. Except for blade contours and angles, the compressor was similar to the axial compressor as it is known

today. The patent also provided for the cooling of the turbine blades by either water or other suitable fluid.

During the years 1900-08 the Parsons Company built about 30 axial compressors (Fig. 7), the largest having a capacity of 50,000 cfm. The highest delivery pressure of any of the units was 11.75 psi gauge. Much effort was expended with inconsequential success in improving the efficiency of the axial compressor. Primarily because of his numerous other activities but also because of the higher efficiency centrifugal compressor of Rateau, introduced commercially in 1908, Sir Charles finally abandoned further research on the axial compressor.

First practical gas turbines

The Société des Turbo-moteurs in Paris during the years 1903 to 1906 built several experimental gas turbines operating on a cycle similar to that of the modern combustion gas turbine. The work, really the first significant attempt at building a practical gas turbine, was performed by Armengaud[7,8] and Lemale. The results of the original tests obtained on a 25 hp DeLaval turbine led to the construction of a turbine of higher capacity, consisting of a two-row impulse wheel with provision for water cooling of the blades and disk.

Compressed air from a multi-stage Rateau compressor driven by the turbine was supplied to a combustion chamber in which liquid fuel was burned (Fig. 8). The resulting combustion gases, cooled by water injection, were expanded through the turbine. A thermal efficiency of slightly less than three percent was obtained. Notwithstanding this poor performance, the experiments were significant because this was probably the first combustion gas turbine to actually produce useful work.

In 1908 Karavodine[5], in Paris, built a 2 hp, single stage, 10,000 rpm, impulse turbine operating on the explosion cycle with an open type combustion chamber. Four nozzles were circumferentially spaced around the rim of the 6 in. diameter wheel. Connected to each nozzle was a separate, waterjacketed combustion chamber wherein the explosion of the charge caused an increase in pressure and the gases expanded through the nozzle onto the wheel. The cycle repeated itself after the suction effect of the departing gases drew in a fresh charge. The explosions were timed to occur consecutively around the wheel periphery. The combustion chamber was referred to as the "open" type because no valves were placed between the explosion region and the nozzle inlet, compression being effected by the inertia of the burning gas mixture. Although the turbine reputedly operated satisfactorily, the overall thermal efficiency amounted to less than three percent.

Holzwarth turbines

In 1908 Dr. Hans Holzwarth[9] began his long years of experimental work on the explosion type of gas turbine which bears his name (Fig. 9). The continued activity and interest exhibited in this turbine by Holzwarth and others has persisted to the present day.

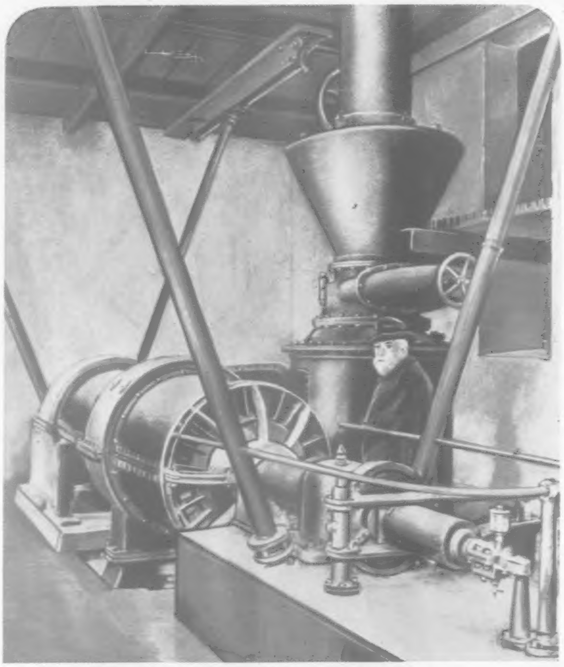


Fig. 5 — The Stolze "Fire Turbine," 1872.

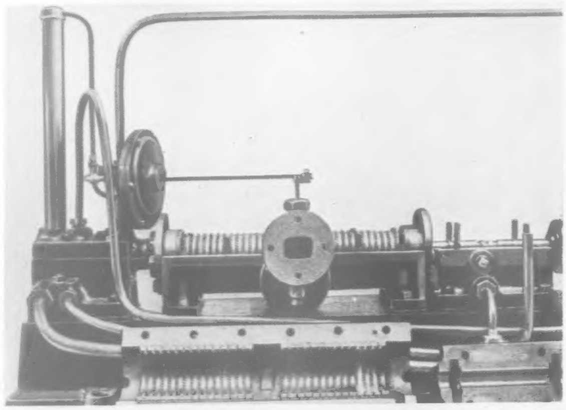


Fig. 6 — Early Parsons Turbine, 1884.

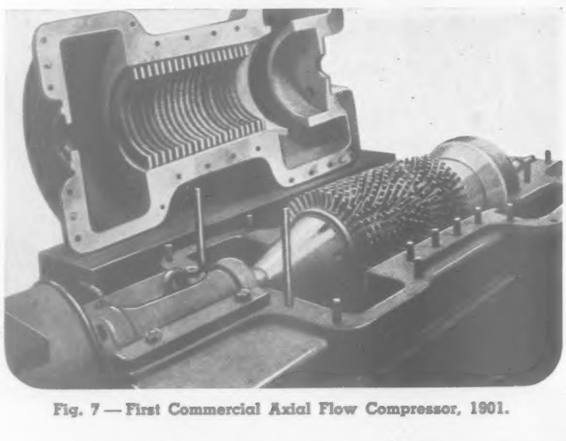


Fig. 7 — First Commercial Axial Flow Compressor, 1901.

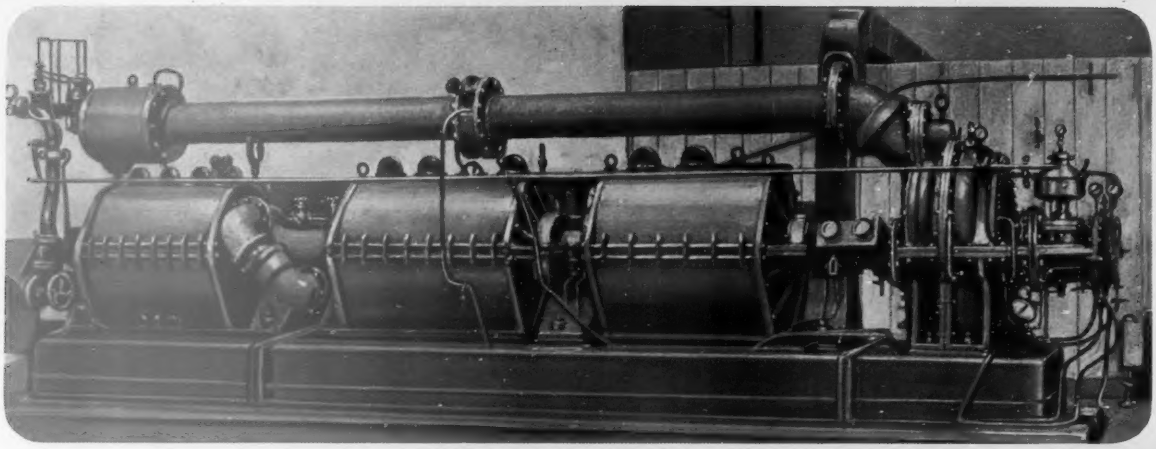


Fig. 8 — Gas Turbine of Société des Turbo-moteurs, 1905.

The Holzwarth turbine operates on the explosion or Otto cycle, the expansion phase of the cycle extending to atmospheric pressure. The explosion occurs upon ignition of a charge of air and gas introduced under pressure into the combustion chamber. The pressure in the closed chamber increases until it overcomes the action of a spring-loaded valve, permitting the gases to flow to a nozzle whence they are discharged at high velocity onto a turbine wheel. The nozzle valve is specially constructed so that it remains open under oil pressure until the combustion chamber is emptied. Expansion is followed by a scavenging operation which clears the combustion chamber of residual burnt gases and also cools the turbine blades. After scavenging, a fresh charge is admitted and the cycle repeated.

Precompression of the charge was not provided in the first turbine built by Holzwarth, but later ones had a moderate amount produced by a steam turbine-driven compressor. A waste heat boiler located in the exhaust passage of the gas turbine supplied steam for the compressor turbine which operated condensing in order to furnish sufficient power to effect compression.

Holzwarth turbines have been built by the Körting Company of Hanover, Maschinen-Fabrik Thyssen and Company of Mulheim on the Ruhr, and the Brown, Boveri Company of Baden[10]. In spite of the long period of development, reports infer that there are only several Holzwarth turbines in operation today. However, notwithstanding this limited number, Dr. Holzwarth and his associates deserve considerable credit for their unyielding efforts in furthering the gas turbine art.

Published test results of the Holzwarth turbines appear to have unsatisfactory interpretations, but Stodola has concluded that the highest overall thermal efficiency obtained in any of the experiments performed up to 1927 is about 13 percent.

Limitations of earlier units

No attempt has been made, in the foregoing historical review, to record all of the information available, but rather only that which had a predominant influence on gas turbine progress. A recounting of each of the thousands of patents granted pertaining to gas turbines would be prohibitive and of doubtful necessity. Therefore, only items of apparent major importance have been included.

Recapitulating, review of past practice has indicated the need of a simple, efficient, and reliable gas turbine. Associated with the few machines that actually operated were either low efficiency or complex construction — the latter feature greatly jeopardizing the possibility of achieving a dependable unit.

Not included in this analysis are exhaust gas turbines used for supercharging because, even though they admirably serve their particular purpose, their limited capacity and field of application precludes their consideration as a prime mover.

These prefatory remarks have indicated the limitations of previous machines. The following section will be devoted to a description of the modern combustion turbine, which has been made commercially practicable only comparatively recently, and is believed to compensate adequately for the deficiencies exhibited

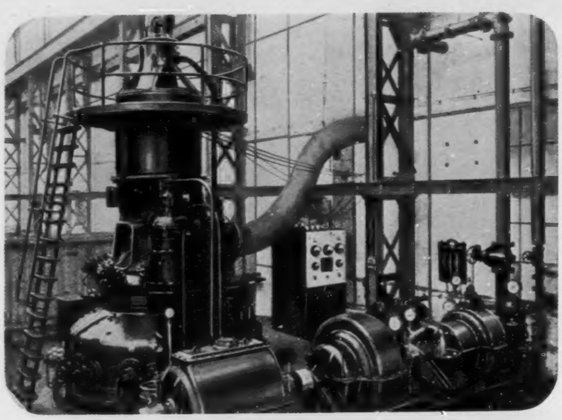


Fig. 9 — The Holzwarth Gas Turbine, 1910.

by earlier gas turbines. Much of the pioneer development work on the gas turbine to be described has been conducted by Brown, Boveri & Co. in Switzerland.

Modern combustion turbine

Simplicity is one of the distinguishing features of the modern combustion gas turbine. Absence of the many diverse appendages characteristic of previous types has undoubtedly contributed to the commercial success which it has attained. Basic constituents of a combustion turbine unit are a gas turbine, compressor, combustion chamber, and fuel equipment. Supplementing these with a generator, lubrication system, control apparatus, and a means for starting completes a power plant significant primarily because of its lack of the veritable myriad of auxiliaries necessary for steam plant operation. Furthermore, since its working medium, air, is universally available and because water is not required in its operation, the gas turbine plant enjoys the added unique advantage of being independent of geographical location.

The arrangement of a modern combustion gas turbine unit is depicted schematically in Fig 10. Air from the atmosphere is compressed in a multi-stage axial flow compressor "B," driven by a reaction type gas turbine "A." Liquid or gaseous fuel injected at "C" is burned with part of the air discharged from the compressor; the remaining, and greater, part flows through the annular space "F" and, upon emerging, mixes with and cools the products of combustion to a suitable turbine inlet temperature. Expansion of this gas to atmosphere in the turbine produces more power than that required to effect compression of the air, and the excess power is supplied to a generator "D." For starting purposes a motor "E" is provided to bring the unit up to approximately 25 percent of normal running speed, beyond which the turbine is capable of driving the compressor unassisted.

A speed governor, regulating the fuel supply and thereby the turbine inlet temperature, affords the necessary control equipment. If a designated overspeed is exceeded, an emergency governor actuates a valve causing the gas to by-pass the turbine. Balance pistons are not required since the axial thrusts of the turbine and compressor, being equal and opposite in direction, are effectively neutralized through the solid coupling connection. A thrust bearing is provided, however, to absorb any slight axial unbalance that may inadvertently exist.

The principal commercial application of the combustion gas turbine in this country has been in oil refineries employing the Houdry process, a catalytic cracking method of manufacturing gasoline. Air, discharged from the axial compressor, after being used in the process is returned to the turbine as a high temperature gas which, upon expansion, produces power to drive the compressor. The excess power is furnished to the generator. In this arrangement no combustion chamber is required since the process itself acts in this capacity.

To fulfill the air requirements of various installations embodying this application, units having compressor capacities of 16,000, 23,000, 40,000, and 60,000 cfm have been constructed. A section through the gas turbine for a 40,000 cfm unit is shown in Fig. 11. Neglecting the numerous details, reference will be made to only the major parts.

A solid chrome-nickel-steel forging comprises the turbine spindle (1) on whose periphery are inserted five rows of reaction blading (6), to be described more fully later.

The turbine casing, split on the horizontal center line, is cast of carbon-molybdenum steel. The gas inlet passage (3) and exhaust passage (4), both located in the same vertical plane, are cast integrally with their respective cylinder halves. Five rows of reaction cylinder blading (5) are inserted in grooves machined in the casing. A by-pass connection (26) joins the inlet and exhaust regions through a valve (32), operated by an emergency governor (10) which is actuated by a centrifugal stop bolt (13) when overspeed conditions exist.

Labyrinth glands (19) are provided to prevent leakage of gas to atmosphere where the turbine spindle ends emerge from the casing. To reduce gas leakage further, sealing air from the compressor discharge is injected at a suitable point (17) in the glands.

Conforming to certain requirements of the oil refinery units are the roller bearings (21) shown; however, these would be of the sleeve type in a machine designed for power purposes only. A solid coupling (36) joins the turbine spindle (1) with the rotor (2) of the axial compressor.

The turbine cylinder and spindle blades, with spacer pieces, are shown in Fig. 12. The tapered and twisted spindle blades, milled from 19 percent chrome-9 percent nickel steel containing small amounts of tungsten, molybdenum, titanium, and columbium, are securely held in place by the engaging of the upset end of the blade with the serrated spacer pieces. The cylinder blades, made from a straight rolled section of 15 percent nickel steel, have inlet edges air-hardened to prevent erosion and are fastened in their grooves by the engaging of a projecting ring in the groove with a slot in the blade and the close-fitting spacer pieces.

Compressor construction

A sectional view of the axial compressor used on a 40,000 cfm unit is shown in Fig. 13. The forged steel rotor (1) consists of a shaft end, having a hollow cylinder for the spindle proper on which the rotating blades (6) are mounted, and a drum with the other shaft end. The hollow cylinder is shrunk onto the drum and locked.

The cast iron casing (3) is horizontally split with intake and discharge openings directed vertically upward and cast integrally with the upper half. The stationary blading (5) is inserted in grooves machined in the inner periphery of the cylinder.

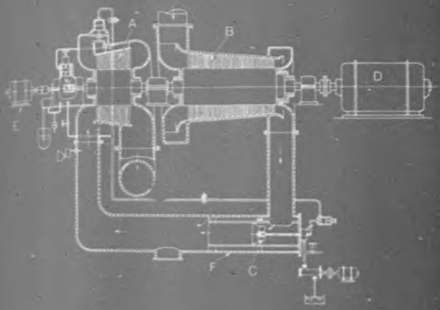


Fig. 10—Schematic Arrangement of Combustion Turbine Unit.

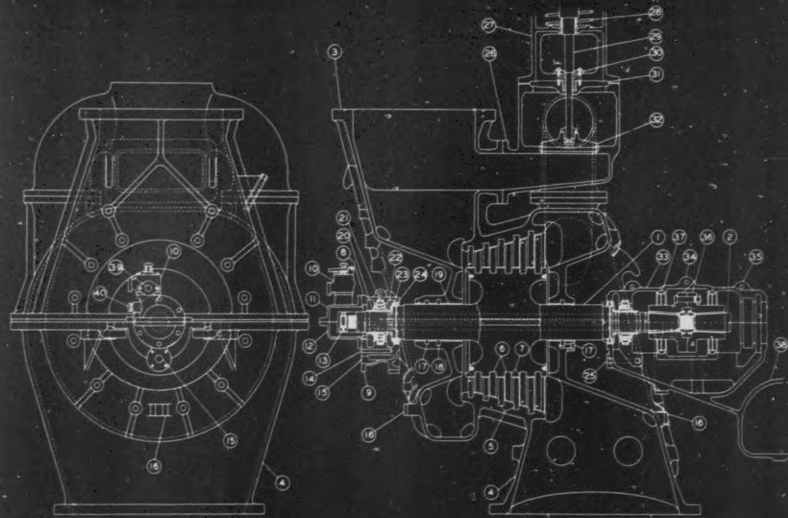


Fig. 11—Section through Gas Turbine of 40,000 Cfm Unit.

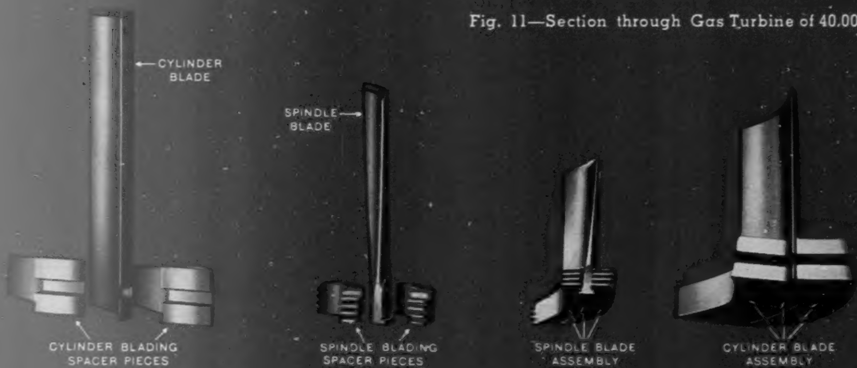


Fig. 12—Gas Turbine Blading.

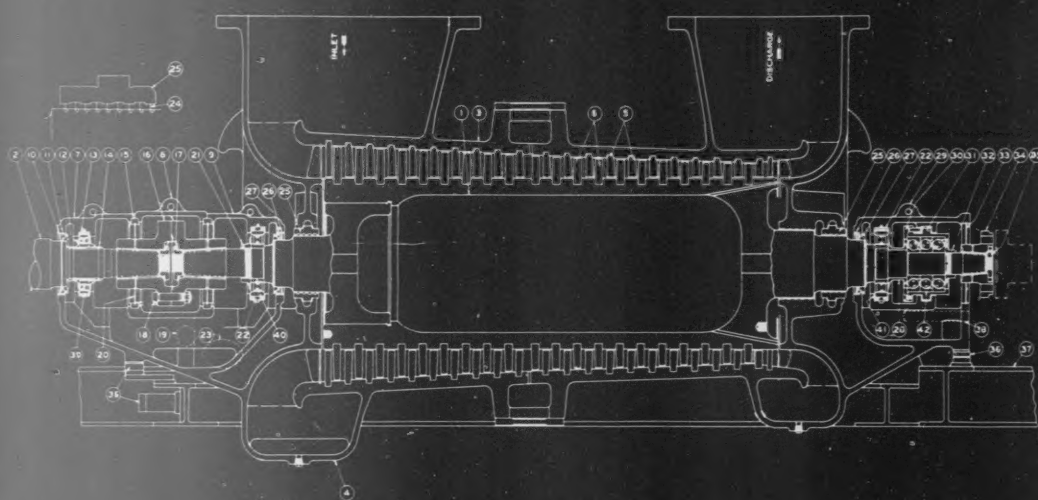


Fig. 13—Section through Axial Compressor of 40,000 Cfm Unit.

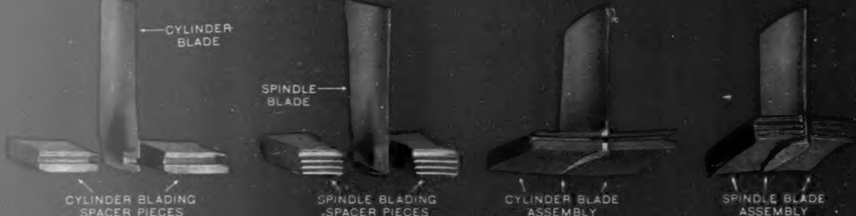


Fig. 14—Axial Compressor Blading.

Where the shaft ends pass through the casing labyrinth, sealing glands (25) are provided. These glands consist of radially projecting fins (24) on the shaft which rotate with close radial clearance in grooves in the casing (25). The turbine glands are similarly constructed.

Roller bearings (40) and (41) are shown; but, as in the case of the turbine, a power unit would be designed with bearings of the sleeve type. A ball type thrust bearing (42) absorbs any sligh. axial thrust that may exist. In a power unit this thrust bearing would be of the Kingsbury type.

The solid coupling (16) transmits the driving torque of the gas turbine to the compressor. The excess power of the unit is supplied to the generator through a gear connected to the coupling end (34).

The cylinder and spindle blading used in the axial compressor is shown in Fig. 14. Since high temperatures are not involved, five percent nickel steel is used as blading material. Root fastenings similar to those described for the gas turbine are used. The cylinder blades are milled and cam ground to airfoil cross-sections that increase in area with the increase in height measured from the root support. Aerodynamic requirements dictate such contours in order to produce a high efficiency axial compressor.

Fig. 15 — Fuel burner element removed from combustion chamber.

Fuel burner

A fuel burner element, after removal from the combustion chamber proper, is shown in Fig. 15. Louvers, with provision for external adjustment, assure a suitable apportionment of the air discharged from the compressor so that the correct quantity enters the burner for combustion purposes. The remaining air flows through the annular passage defined by the combustion chamber wall (not shown) and the steel liner. Deflectors located in this passage impart a

Fig. 16 — A 23,000 cfm gas turbine-axial compressor unit with top casing removed.

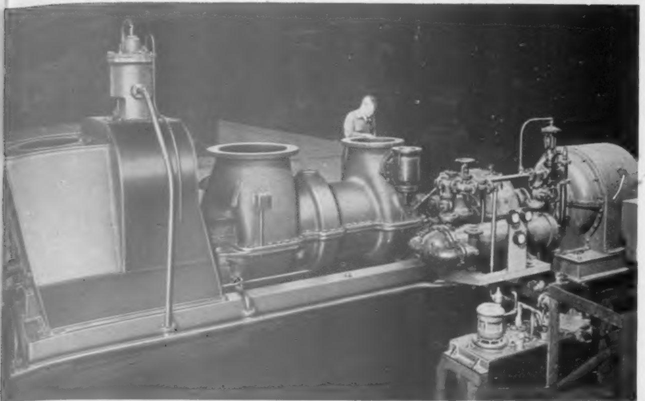


Fig. 17 — A 40,000 cfm gas turbine-axial compressor unit without combustion chamber.

whirling motion to the air, creating a turbulent condition which produces a thorough subsequent mixing with the products of combustion emerging from the central portion of the liner.

A partially assembled 23,000 cfm gas turbine-axial compressor unit is shown in Fig. 16. Mounted on a common baseplate, the 6-stage turbine at the left is directly coupled to a 21-stage compressor at the right. This unit, operating at 6000 rpm, is geared to an 1800 rpm generator, not shown. Lashing wires, installed in the first stationary and last two rotating blade rows in the turbine, increase the vibrational frequency and reduce the bending stresses in the blades. Roller bearings and labyrinth sealing glands may be clearly seen.

A 40,000 cfm gas turbine-axial compressor unit without a combustion chamber is shown in Fig. 17.

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WHAT'S THE ANSWER?

Question—When buying switchgear equipment, current transformers are required for relaying and metering. What rules shall be followed when specifying them?—R. H. L.

Answer— Current transformers are designed and manufactured for certain standard continuous current ratings. In specifying the current rating desired, a standard rating should be selected which is higher than the normal circuit current by such an amount that a satisfactory margin for overload conditions is provided. Usually this rating selected will be from 25 percent to 50 percent above the normal current expected in the circuit.

Standard switchgear current transformers are designed with the highest accuracy compatible with the necessary thermal and mechanical through-current characteristics. It is usually not desirable to specify the accuracy required unless the accuracy of metering on the circuit involved is so important that it is feasible to pay extra for higher accuracy and perhaps sacrifice through-current capacity, thus assuming the attendant risk of failure under short circuit conditions.

Ordinarily the only ratings of standard current transformers on which good metering accuracy is not maintained are the low current ratings. Since these transformers are seldom used to meter for revenue purposes, higher accuracy is not essential. It is also well to remember that for a given percentage error, the low current rating transformer will show less power loss in metering than will a higher current rating transformer. Seldom, if ever, is it necessary to call for other than standard accuracies on transformers used for relaying purposes.

When purchasing current transformers built to standard A. I. E. E. and N. E. M. A. switchgear standards, it is usually desirable to specify only the required current rating since these standards insure getting transformers with the proper thermal and mechanical characteristics. When it is considered necessary to specify the accuracy, it should be done only on the particular transformers where such accuracy is necessary. At the same time the minimum through-current characteristics permissible should be given, with the realization that meeting such specification may involve special transformers at a higher cost.

"What's the Answer?" is conducted for the benefit of readers of ELECTRICAL REVIEW who have questions on central station, industrial or power plant equipment. Send all questions to the Editors of ELECTRICAL REVIEW.

"BREAKER OPERATION, PLEASE". . .

. . . is a call that must be instantly obeyed. A systematic analysis of the apparently complex operating systems discloses surprisingly simple underlying principles of operation.

P. L. Taylor

SWITCHGEAR DIVISION • ALLIS-CHALMERS MANUFACTURING COMPANY

● The American Institute of Electrical Engineers defines a circuit breaker as ". . . a device for interrupting a circuit between separable contacts under normal or abnormal conditions . . ."

Primarily, a circuit breaker is an automatic protective device used to break the connection between the power source and equipment which may be endangered by a fault in the line. Disconnection isolates the fault, preventing the communication of trouble to other parts of the system and damage to generators, transformers, lines, and other equipment, which can be caused by a prolonged flow of heavy short circuit currents. It also prevents further damage to apparatus and insulation at the point of the fault. Since the heat produced is proportional to the square of the current flowing, it is obviously essential that heavy fault currents be interrupted in a minimum of time.

Many short circuits, particularly on transmission lines, are of a transitory nature; and, in such cases, permanent disconnection of the faulted section of a system is not desirable since the loss of service would be unnecessarily prolonged. Further, in such cases, if the circuit can be reclosed immediately, very little connected load will be lost. It is therefore frequently necessary to arrange a circuit breaker in such a manner as to obtain disconnection of the faulted section for a short time, followed by its reconnection through the automatic reclosing of the circuit breaker. Since the occurrence of transitory faults is far more frequent than the occurrence of permanent faults, most modern circuit breakers, particularly for outdoor installation, must be designed to accomplish repeated reclosing operations satisfactorily.

Actually, the average breaker is seldom called upon to interrupt short circuits or overload currents. A more frequent duty is that of switching; but for the major part of the time the duty of a circuit breaker is to carry load current.

In spite of the fact that a circuit breaker remains mechanically inert only slightly less than 100 percent of the time, it must be ready to open or close positively, quickly, and repeatedly at any time with a speed and motion characteristic that assures proper and efficient closure and interruption of the circuit on which it is installed. This it must do under the conditions of limited closing power and trip energy and widely varying operating voltage and ambient conditions. Thus, *the basic problem of circuit breaker operation is to maintain at all times sufficient degree of coordination throughout the mechanical system to the breaker contacts to assure rapid and efficient operation of the breaker continuously.*

The mechanical system

The mechanical system of a circuit breaker consists of three main parts:

1. The operator, which furnishes the closing power and the tripping means.
2. The pole unit mechanism, which translates the power and motion characteristics of the operating mechanism into the functional requirements of the particular breaker.
3. The connecting linkage between the operator and the pole unit mechanism.

Correct adjustment of, and coordination between, all three main parts is obviously necessary to obtain proper mechanical and electrical operation of the breaker.

The operator, or operating mechanism, may be manual, electrical, or pneumatic. For economic reasons, it is usually built as a separate unit designed for use on several types or ratings of breakers. Most operators are of the electrical solenoid type, operated either directly from a direct current source or from an alternating current source through a dry type rectifier. The operator also provides the latching and tripping means for the breaker. Modern breakers, while power closed, are usually opened by gravity assisted by accelerating springs.

Operating mechanisms used with indoor breakers are usually designed to be adaptable to various mountings relative to the breakers which they operate. Because the primary function of a circuit breaker is to interrupt the circuit instantly, most modern operating mechanisms are mechanically trip-free; i. e., the breaker is free to open when the tripping means is actuated due to the occurrence of a fault, even though the closing solenoid or other closing means is energized.

Operators can also be made electrically trip-free by the use of a trip-free control relay which has provision for de-energizing the solenoid or other closing means even though the control relay remains energized. This prevents reclosure of the breaker until after the closing relay operating coil has been de-energized to allow the closing relay to reset, eliminating the possibility of "pumping," or inadvertent repeated reclosure and trip-out of breakers on faulted circuits.

The pole unit mechanism is an integral part of the breaker unit proper and is designed and built to meet its particular operating requirements. The same pole unit mechanism is ordinarily used for a particular breaker type, regardless of the type of operating mechanism and connecting linkage arrangement. Most modern pole unit mechanisms are of the type designed to give essentially a straight line motion to the circuit breaker lift rods carrying the moving contacts.

Principle of circuit breaker operation

Perhaps the best approach to a discussion of the operation principles of present-day circuit breaker mechanisms is a review of the basic arrangements. Fig. 1 shows a development of the problem from the simplest *possible* arrangement to the simplest *practical* arrangement of operating means using a non-trip-free solenoid operator.

With a non-trip-free operator, the closing force is transmitted directly from the power element to the breaker contacts until they are fully closed. At this point the mechanism latches, and the breaker is held in the closed position when the closing force is removed. The breaker is opened by tripping the latch after which the contact reaction and gravity cause it to open. A breaker having a non-trip-free operating mechanism cannot be opened while the closing element is energized.

Figure 1a shows an elementary non-trip-free operator directly connected to the circuit breaker lift rod. No pole unit mechanism is used, and no mechanical advantage is possible since a straight line relation obtains between the solenoid and the breaker moving member. The solenoid stroke must be the same as the breaker stroke, and the load on the solenoid is equal to the breaker reaction throughout its stroke. The latch must carry the full breaker-closed reaction, making it hard to trip. Long stroke solenoids are extremely inefficient and are impractical to build in large sizes because of current and space limitations.

Figure 1b shows the introduction of a pole unit mechanism consisting of a simple lever by means of which it is possible to reduce the stroke of the solenoid. The latch reaction, however, suffers an increase, and the circuit breaker lift rod no longer has a straight line motion.

Figure 1c shows the insertion of a simple toggle which introduces variable force and stroke relations between the operating mechanism and the breaker moving member. It also reduces the amount of closing force required during the latter part of the stroke. The nearer the toggle approaches dead center when the breaker is in the closed position, the less the latch reaction, making the breaker easier to trip. If, however, the toggle is permitted to go too close to dead center, the collapsing reaction on the toggle will not be sufficient to start the breaker moving parts in the

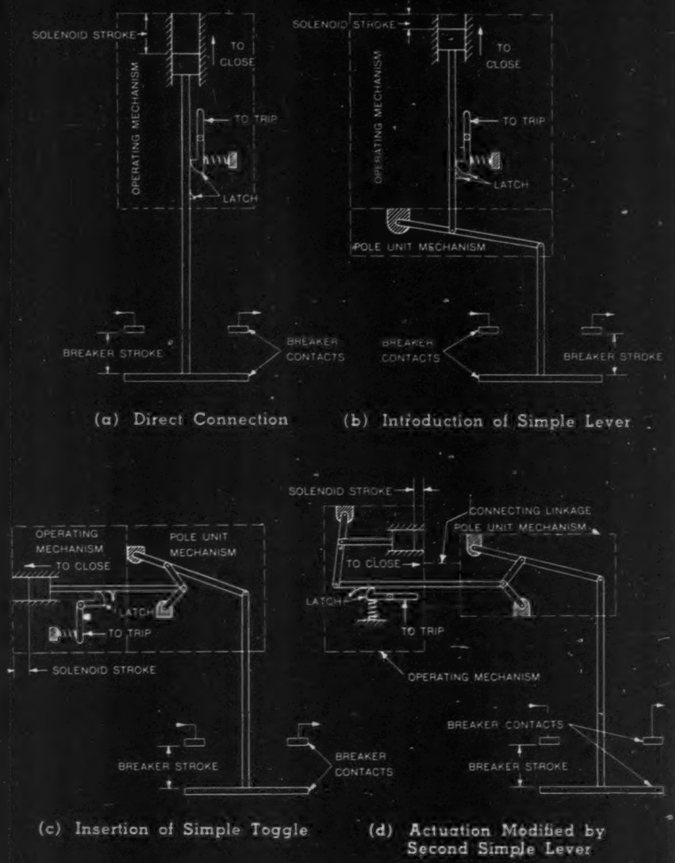


Fig. 1 - Development of Basic Operating Means.

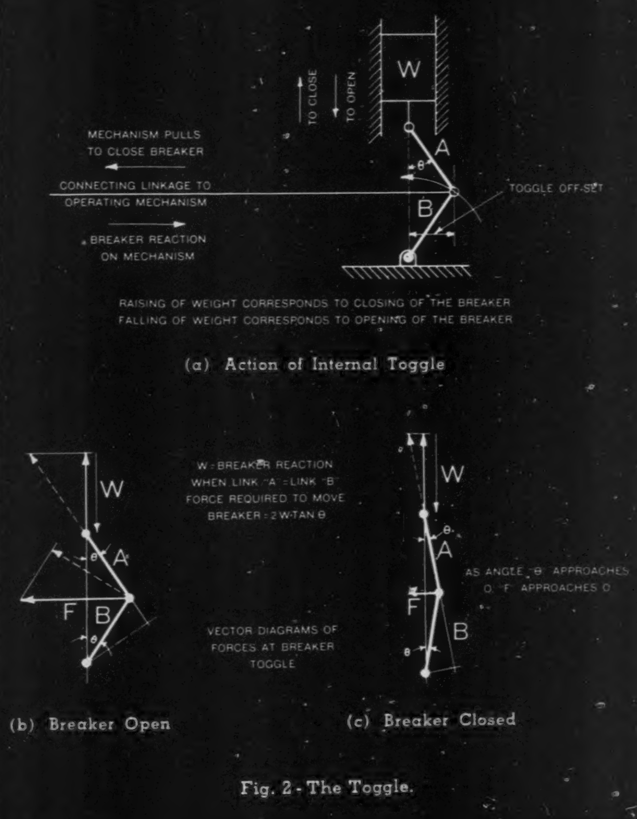


Fig. 2 - The Toggle.

opening direction against friction. If the toggle is carried over center, the mechanism will lock in the closed position.

Figure 1d shows a structure similar to that of Fig. 1c but modified by the insertion into the operating mechanism of a simple lever to reduce the solenoid armature travel in order to obtain the increased solenoid efficiency resulting from the shorter solenoid stroke. The pull of a solenoid is inversely proportional to the square of the gap distance between the solenoid armature and the pole-head toward which the armature is pulled when the solenoid is energized.

Toggles

The toggle (and its close relative, the cam) in its various forms is one of the most important elements used in circuit breaker mechanisms. By varying the position and adjustment of various toggles, the breaker operating characteristics can be varied widely, and misadjustment may even render the breaker inoperative.

Referring to Fig. 2a, a toggle is a combination of two links A and B connected in series; the outer end of link B is hinged at a fixed center, and the outer end of the link A is connected to the load W. Rotation of link B toward the point where the center lines of the two links constitute one straight line (i. e., such as to cause progressive reduction of angle Θ) results in upward motion of the load.

It will be apparent that the greater the toggle is offset (i. e., the larger the angle Θ), the greater the distance through which load W will be moved per degree of rotation of link B and, therefore, the lower the mechanical advantage. As the toggle offset decreases, the movement of the load per degree of rotation decreases; and the mechanical advantage increases until, when Θ approaches zero, the load movement per degree is extremely small, the mechanical advantage is very high, and a relatively small rotational force applied to link B will support the load.

Figures 2b and 2c show vectorially the relative forces involved for large and small degrees of toggle offset respectively. Theoretically, in the "on center" position a zero force applied at the center point of the toggle will support an infinitely large force applied across the toggle. Conversely, an infinite force applied across the toggle will result in zero force tending to break the toggle and open the breaker.

Figure 2a shows the action of an internal (or pole unit mechanism) toggle. The connecting linkage to the operating mechanism can be connected to the center point of the toggle, as shown, or to another lever having the same fixed center as link B. Fig. 2b corresponds to the toggle position with the breaker open, and Fig. 2c indicates the toggle position with breaker closed.

Incorporation of a toggle into the pole unit mechanism has the following advantages and disadvantages:

Advantages

1. Reduction of the closing energy required during the latter part of the stroke when it is necessary to offset increased mechanical loading caused by:

   a. Breaker contact (mechanical) reaction.

   b. Compression of opening springs.

   c. Electromagnetic throw-off forces caused by flow of current through the loop formed by the bushings and the contact bridge.

2. Limitation of the stress in the operating mechanism parts including the latches.

3. Reduction of the load on the tripping latch, resulting in reduction of the force required to release the latch.

Disadvantages

1. Reduction of the initial speed of travel in opening, caused by the small component of force tending to collapse the toggle and open the breaker when the breaker is in the closed position.

2. Reduction of mechanical advantage at the beginning of the closing stroke.

The disadvantage of the poorer mechanical characteristic near the open position can be quite readily overcome. The relatively slower initial motion in opening has been no particular disadvantage on standard speed breakers; but, to meet some of the more exacting requirements for ultra-high-speed operation, it is necessary to allow a greater component of breaker reaction to fall on the tripping system in order to obtain higher initial opening speed. This is done by setting the internal toggle farther off center or eliminating it entirely. An external toggle, located in the operating mechanism on the solenoid side of the trip-free elements, is added in order to retain the necessary mechanical advantage for the solenoid.

The main breaker toggle, usually referred to as "the toggle," whether internal or external, is usually a full toggle as shown in Fig. 2a. Other cranks and levers arranged in toggling relation are employed at various points in the mechanism. An excellent rule in case of closing or tripping difficulty is to *first check to determine that the (main) toggle is in the properly coordinated relation with the operating mechanism and the breaker contacts.*

Pole unit mechanisms

Most modern pole unit mechanisms are of the straight-line type in order to obtain accurate registry of the breaker contacts when entering interrupting devices.

The typical indoor pole unit mechanism, shown in Fig. 3, consists essentially of a lever (4) having a simple toggle, consisting of a crank (2) and links (3), applied at the short end and having its long end connected to the breaker crosshead through link (5). Closing force is applied to crank (1) as indicated by the arrow. Cranks (1) and (2) are keyed to the same shaft A and move together. During the closing stroke, crank (2) and link (3) act in a toggling relation between the shaft A and the short end of lever (4) which pivots at B. Link (5) permits the breaker crosshead (6) to slide on vertical guide rods (9), thereby resulting in a straight-line vertical movement of the lift rods (11) and in compression of opening kick-off springs (12). The over-travel stop bolt (8) is set to engage the crosshead slightly above the normal closed position to prevent damage to the breaker contacts from over-travel on power closing.

A toggle stop bolt (10) is provided to adjust the toggle offset and to prevent the toggle from going over center into a locking position. When the breaker

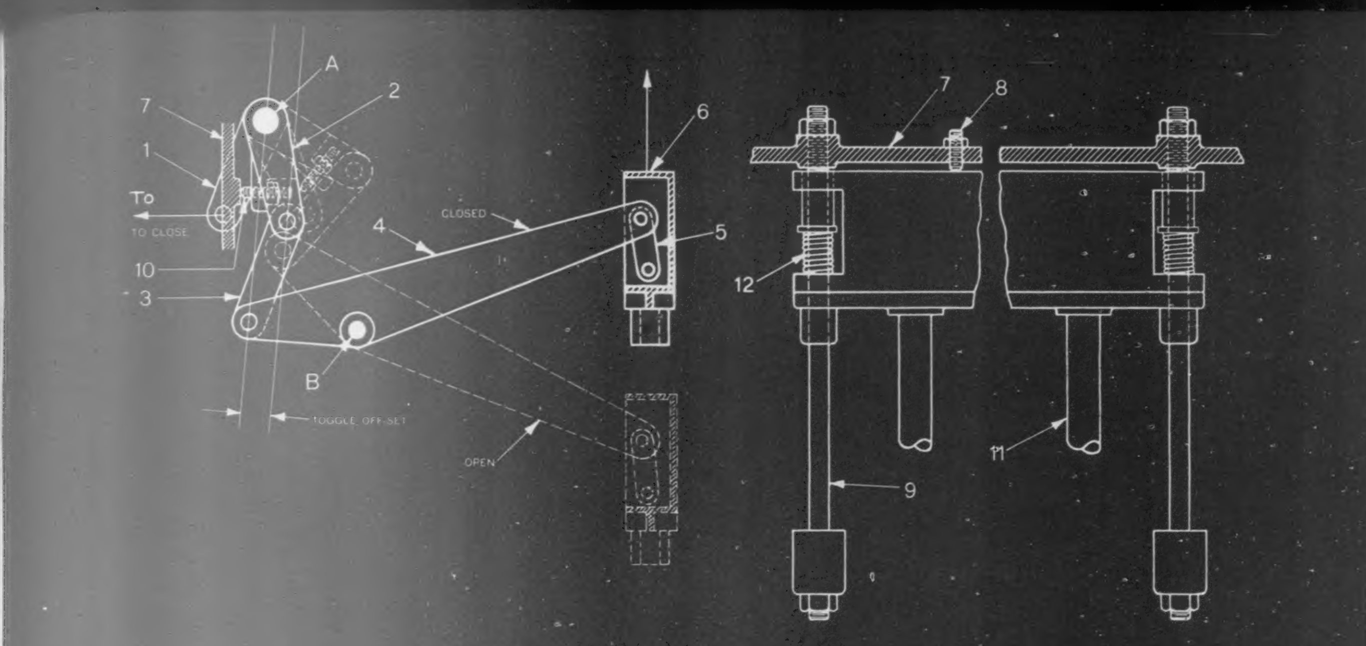


Fig. 3 - Pole Unit Mechanism for Indoor Breakers.

is in the correct closed position, the end of the toggle stop bolt is a short distance away from the breaker head casting (7), thereby allowing for a slight over-travel on power closing and preventing any binding condition that might hinder opening of the breaker if the bolt were permitted to press hard against the casting.

Figure 4 shows a typical outdoor breaker pole unit mechanism of the straight-line type. The closing force is applied to crank (7), as shown by the arrow, by means of interpole connecting rods. The toggle arrangement is similar to that of the indoor pole unit mechanism, cranks (7) and (8) being arms of a common member and crank (8) and link (9) constituting the toggle between the fixed point B and a point on lever (10). Lever (10) and links (3) and (5) are so proportioned that the result is an approximately straight-line vertical motion of the lift rod clamp (4). Items (1), (11), and (12) are the over-travel stop, kick-off spring, and toggle stop bolt, respectively.

Standard speed operating mechanisms

Figures 5 and 6 show one of a typical family of trip-free solenoid operators for use with conventional breakers having an internal toggle, where ultra-high-speed tripping is not required. Connection to the breaker is made at H, or alternatively to a crank I if horizontal instead of vertical motion is required. These points move in the direction of their respective arrows to close the breaker.

Referring to Fig. 6a, showing the mechanism in the open position, A, B, and C are fixed points. During the closing stroke, point D also acts as a fixed point since trip-free latch (13) is restrained by its roll (18). Points D, B, C, E, F, and G constitute a six point parallelogram. In closing, downward movement of the solenoid armature causes one side of the parallelogram E, F, G, to rotate about points C, B, and D respectively, thereby rotating crank (1) or crank (20), (one of which is attached to the breaker at point H or I) around point C, closing the breaker. When the closed position, Fig. 6b, is reached, holding latch (15) engages its roll at the junction of the latching toggle, consisting of crank (2) and link (16), thereby holding the mechanism and breaker in the closed position after the solenoid is de-energized.

Tripping is accomplished by disengaging trip-free latch (13) from its roll (18) which is on trip lever (12), allowing latch (13) to rotate counter-clockwise about point B and point G about point F, until the trip-free cam latch roll (5) runs off cam latch (4), allowing the overhung toggle linkage, consisting of links (3) and (6), to open to the position shown in Fig. 6c, allowing cranks (1) or (20) to rotate about joint C, permitting the breaker to open.

At the point shown in Fig. 6c the rotation of latch crank (13) around point B has caused the main latch lifting screw (19) to raise the holding latch (15), releasing the main latching toggle (2) and (16), allowing a mechanism retrieving spring, located under the solenoid armature, to reset the mechanism to the position shown in Fig. 6a.

Adjustment of the range of tripping reaction for the general class of breaker with which this type of operating mechanism is used is obtained by selecting the proper size of cam latch roll (5). Further adjustment is made by means of the toggle stop screw (7) which regulates the amount of off-center of the overhung toggle E, F, G. The operating mechanism is correlated with the breaker which it operates by the selection of the proper hole in the operating crank (1) at H or by the selection of the proper length of crank (20) to obtain the desired stroke and by the adjustment of the connecting linkage to the breaker. An adjustable connection (10) on the solenoid armature provides for adjustment of the armature to act as a mechanism stop during the closing operation.

High-speed operating mechanisms

Figures 7 and 8 show a trip-free solenoid operator of the "bucking-bar" type, employing an (external) toggle and a compound reaction cam latch system for use where ultra-high-speed tripping is required. This mechanism is typical of the newer types arranged for

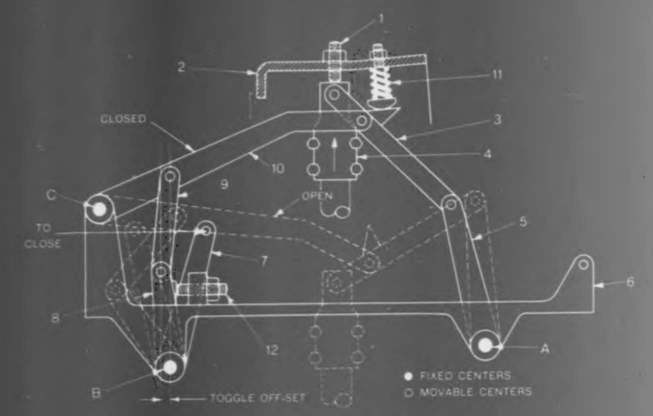


Fig. 4 - Pole Unit Mechanism for Outdoor Breaker.

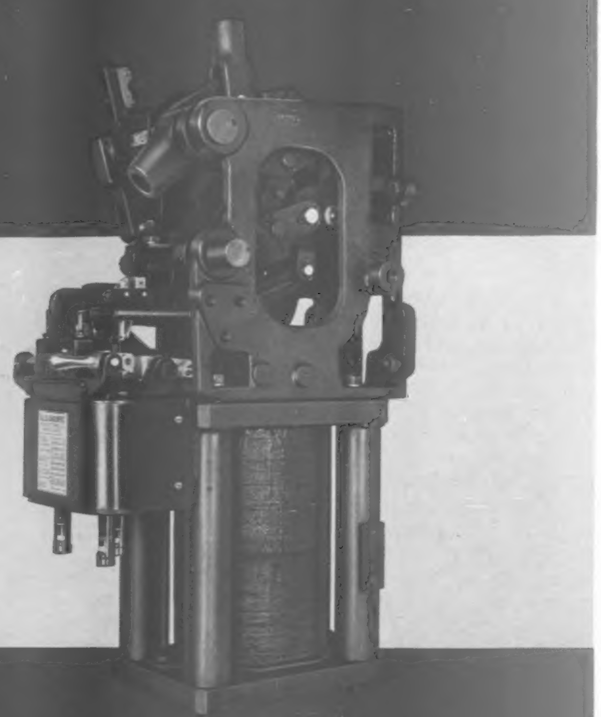


Fig. 5—Solenoid Operator for Conventional Breaker.

ultra-high-speed operation. Connection to the breaker is made at point H (Fig. 8a), which moves downward to close the breaker as indicated by the arrow.

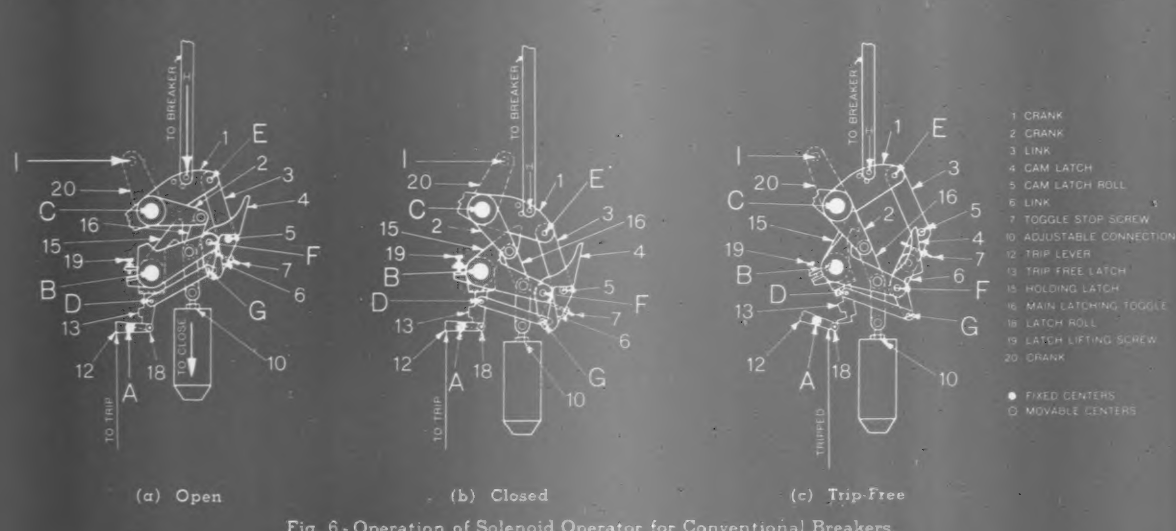
Referring to Fig. 8a, showing the operator in the open position, points A, B, C, D, E, F, and G are fixed points. During the closing stroke, point I also acts as a fixed point since it is restrained in the position shown by the large cam latch (6) and the small cam latch (5). In closing, manual, pneumatic or solenoid actuation of plunger (12) causes it to push upward on the main operating toggle roll (14), thereby operating the main toggle, consisting of crank (15) and link (9), and rotating lever (8) counter-clockwise about its temporarily fixed center I. This rotates crank (11) through link (10) and causes point H to move downward, closing the breaker. When the closed position, Fig. 8b, is reached, the holding latch (17) engages its seat (16), thereby latching the mechanism and the breaker in the closed position.

Tripping is accomplished by unlatching latch (1) from point (2), allowing the overhung toggle, consisting of links (3) and (4), to collapse and the small cam latch (5) to rotate around point B and off its seat on the large cam latch (6). Cam latch (6) then disengages from roll (7), allowing point I to move to the right, in a horizontal guide not shown, permitting the crank (11) to rotate counter-clockwise and the breaker to open as shown in Fig. 8c. After releasing roll (7), cam latch (6) engages the holding latch (17), disengaging it from its seat (16). The compressed resetting springs (13) and gravity then reset the mechanism to the position shown in Fig. 8a.

This type of mechanism is so arranged that the full breaker reaction may be carried by the tripping system, thus obtaining high release speed. Adjustment of the tripping reaction on the trip-free latch on this type of mechanism is achieved by means of shims under the trip-free latch plate (2), thereby adjusting the "off-center" of the overhung toggle. The operating mechanism is coordinated with the breaker which it operates by adjusting the connecting linkage.

Connecting linkages

Outdoor oil circuit breakers, and most large indoor oil circuit breakers, are shipped from the factory with their complementary operating mechanisms integrally



(a) Open (b) Closed (c) Trip-Free

Fig. 6 - Operation of Solenoid Operator for Conventional Breakers.

mounted and with the connecting linkage between the pole unit mechanism and the operating mechanism correctly adjusted.

Many of the small and medium sized indoor breakers are finally installed with a panel mounted between the operating mechanism and the breaker. Such a typical "back-to-back" arrangement is shown in Fig. 9, and it will be apparent that the length of the connecting link between the operating mechanism and the breaker pole unit mechanism depends on the thickness of the panel.

Mounting and remounting of indoor breakers and their operating mechanisms

Many indoor breakers and their operating mechanisms are placed in their final operating relation by switchboard builders, the construction departments of public utilities, contractors and others who may not be intimately familiar with the mechanical design of circuit breakers. Breakers which are to be so mounted are set up and operated with their mechanism by the manufacturer before shipment. Ordinarily, sufficient information is available to the manufacturer to enable him to approximate the final arrangement so closely that no adjustment will be required in the field other than *the proper coordination of the connecting linkage between the mechanism and the breaker. Upon this final coordination of the operating system of the breaker depends to a large extent the proper functioning of the breaker.*

Breakers ordered for back-to-back mounting relationship between breaker and operating mechanism, but supplied without the panel or other intermediate mounting support, are set up, tested and shipped with a temporary spacer between the mechanism and breaker of such thickness as to give the spacing specified by the purchaser. Depending upon the class of breaker, the connection supplied between the breaker and mechanism may be adjustable or may be a non-adjustable link good for one particular spacing only. One of the most common difficulties encountered is due to mounting a breaker, adjusted for a particular back-to-back spacing, on some other spacing without making a corresponding change in the connecting linkage.

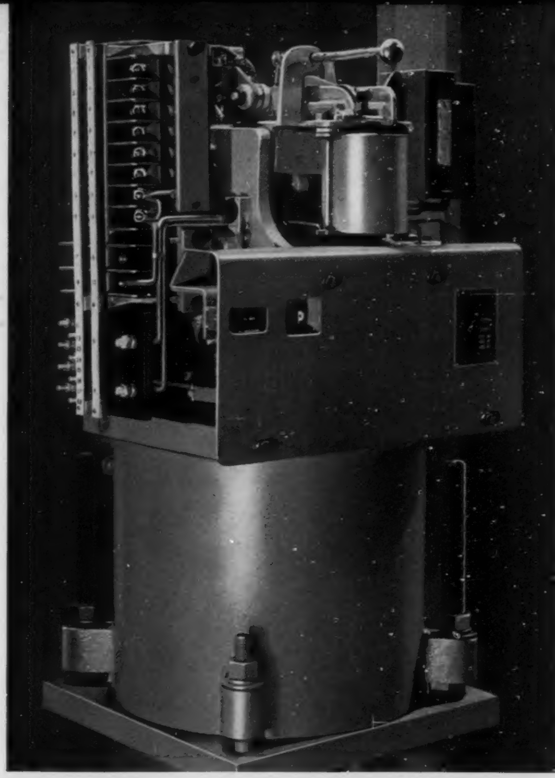


Fig. 7 — High-speed solenoid operator.

As a typical example, assume a small solenoid operated breaker ordered for ¼ in. panel mounting arranged as shown in Fig. 9. The breaker is received with temporary ¼ in. spacer between the operating mechanism and the breaker proper. The shipping mounting and spacer are removed, and the breaker mounted on a ⅛ in. steel panel without readjusting the connecting linkage. The breaker operation is tried manually. It latches too hard, but it does latch. Then the test man finds that the breaker will not close or trip at minimum voltage. He tries the breaker mechanically, looks at the contacts and decides that the contact pressure is too high, so he has the brush rods lengthened or the moving members shimmed down.

He then tries manual operation and finds it somewhat easier. On electrical operation the breaker now

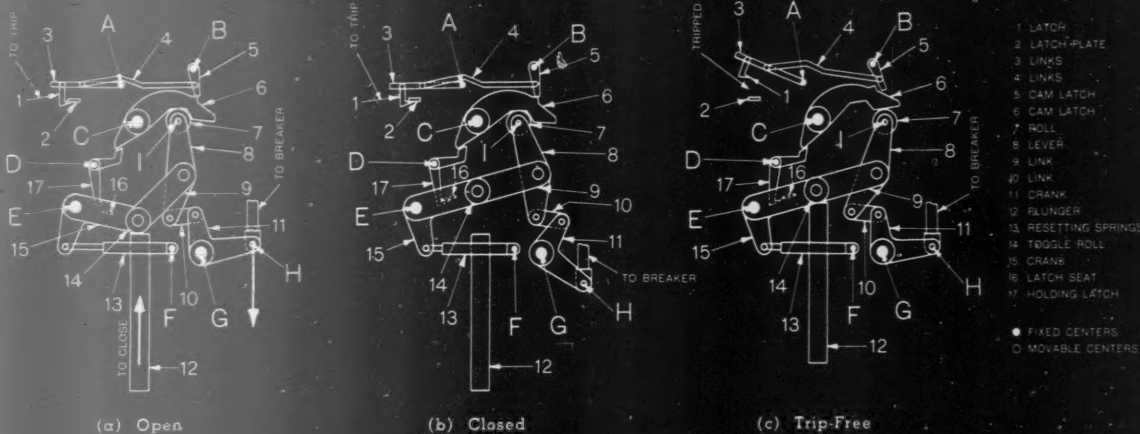


Fig. 8 - Operation of High-Speed Solenoid Operator.

closes at minimum voltage, but on normal closing voltage the operating mechanism trips free, allowing the breaker to fall out about once out of every three times. Thus, a misguided attempt to correct the adjustment of the breaker has resulted in misadjustment of the coordination between the breaker and the operating mechanism when simply shortening the connecting linkage would have corrected the difficulty.

Assume the same breaker ordered for the same panel thickness (¼ in.) but assume it is mounted on a ⅜ in. panel. The construction man installs the breaker as before and tries it manually — it closes and latches satisfactorily. The tester operates the breaker electrically and it operates satisfactorily, but he notices that the main brushes do not make properly. In order to get adequate contact he has the brush rods shortened or moving member shims removed and then finds that the breaker will not close or trip at minimum voltage. Again, misadjustment of the coordination between the breaker and the operating mechanism has resulted when a lengthening of the connecting linkage was all that was necessary.

In the cases cited a little time spent by the construction man in checking the material specifications with the construction details or in familiarizing himself with the few simple mechanical principles involved would have saved time and money. *It is of the utmost importance that a complete analysis of any difficulty be made and the real cause of the trouble determined before proceeding with any readjustment.*

When breakers are arranged for remote operation involving the use of extra bell cranks and operating pipes, particular care has to be exercised to make sure that the bell cranks are accurately aligned and that the pipe lengths are correct in order to avoid binding and springing. To obtain maximum operating efficiency, all bell crank arms should be arranged to move an equal distance each side of the tangential position (the position at which the bell crank arm and the operating pipe connected to it are at 90 degrees). Where several bell cranks or unusually long pipe runs are used, it is often necessary to provide additional accelerating springs to compensate for the inertia and friction of the system.

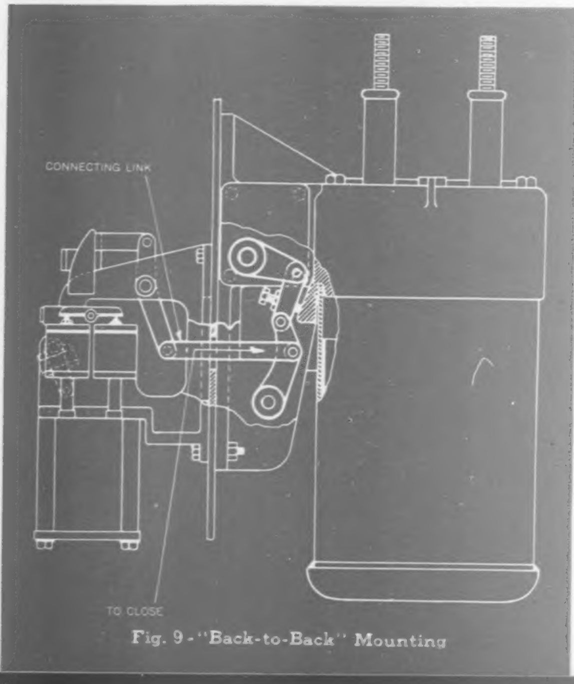


Fig. 9 - "Back-to-Back" Mounting

Operating power supply

AIEE and NEMA Standards specify a standard operating voltage range *at the terminals of the operating device with the operating device energized,* over which range the mechanism should operate correctly.

The selection of a storage battery or other supply source has to be based on the *regulation of the source at the conclusion of whatever period of other emergency duty may be specified and the size and length of conductor to the breaker operating device.* For example, a storage battery may be selected so that, when in a condition of minimum charge, it will supply emergency lighting, pilot lights, etc., for a period of two hours, at the end of which time it will deliver, *at the terminals of the largest and most remote breaker, not less than 90 volts, with the solenoid energized.* The requirements of a battery for circuit breaker operation are a matter of regulation rather than ampere-hour capacity since the time required to operate a breaker is very short and the ampere-hour consumption correspondingly small.

Maintenance

All circuit breaker mechanisms require regular, systematic and thorough inspection. All bearing surfaces of operating mechanisms should be lubricated with a good quality, light, non-gumming lubricating oil having a pour point below 40 C. Occasional operation of breakers also aids in insuring continued free operation of mechanical parts.

Conclusion

The basic problem of circuit breaker operation is to maintain at all times a degree of coordination throughout the mechanical system to the breaker contacts that will continuously assure the rapid and efficient operation of the breaker.

A new breaker, or any breaker not known to be in properly coordinated adjustment, should not be power operated until the coordination has been checked and satisfactory manual operation has been obtained.

Circuit breaker mechanical systems are relatively simple, but caution must be exercised in making adjustments since any change in adjustments usually affects more than one operating characteristic. A readjustment which apparently corrects a particular condition often affects the overall coordination adversely and may even result in improper operation or damage. It is of the utmost importance that a complete analysis of any difficulty be made and the real cause of the trouble determined before proceeding with any readjustment. Small changes in adjustment often produce large results, particularly on the more important breakers.

In order to insure continuously good service through the maintenance of properly coordinated mechanical and electrical relations, a regular and systematic schedule of intelligent and understanding inspection and maintenance is essential.

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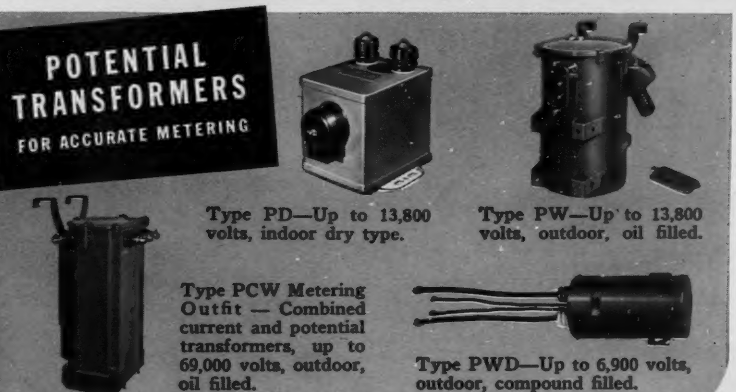

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